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Report AFRPL-TR-66-164

374220

FOURTH QUARTERLY REPORT

FEASIBILITY DEMONSTRATION OF A SINGLE CHAMBER CONTROLLABLE SOLID ROCKET MOTOR (u)

CONTRACT AF 04(611)-10820

CHARLES T. LEVINSKY
GERALD F. KOBALTER

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CHARLES T. LEVINSKY
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JULY 1966

ROCKET PROPULSION LABORATORY
EDWARDS AIR FORCE BASE, CALIFORNIA

AEROJET-GENERAL CORPORATION
A SUBSIDIARY OF THE GENERAL TIRE & RUBBER COMPANY

FOREWORD

This is the fourth quarterly report of Contract AF 04(611)-10820 covering the technical effort from 1 April through 30 June 1966. This report is submitted in partial fulfillment of the contract work statement and reports on the effort completed in the above mentioned time period. The contract involves the exploratory development of a single-chamber controllable solid rocket motor. Work on this program is being performed by the Research and Technology Operations of the Aerojet-General Corporation under the direction of the Rocket Propulsion Laboratory of the Air Force. Work on this contract was initiated 1 July 1965 and is scheduled for completion 31 December 1966.

This report contains information, data, and figures that are classified CONFIDENTIAL. The classified information falls under the Group IV downgrading category, downgraded at 3 year intervals and unclassified after 12 years.

UNCLASSIFIED ABSTRACT

This report deals with the technical effort conducted during the fourth quarter of Contract AF 04(611)-10820, Exploratory Development of a Single-Chamber Controllable Solid Rocket Motor. During the first three quarters of this program, a preliminary design phase, a propellant development phase, a subscale motor design and development phase, and part of a heavyweight motor development phase of effort were conducted. Work performed in this area was reported in the first three quarterly reports, AFRPL-TR-65-204, AFRPL-TR-66-12, and AFRPL-TR-66-99. This report covers the completion of the heavyweight motor development phase, the lightweight motor design effort, and the propellant re-evaluation effort. The final heavyweight motor test results are presented along with photographs and test data. This motor was test fired at altitude and was successfully extinguished once. During the second extinguishment attempt, the motor continued to burn, probably due to a malfunction of the altitude diffuser facility combined with a high propellant burning rate at low pressures. As a result of this second test firing of the third heavyweight motor, the facility is being modified and a propellant re-evaluation effort has been initiated. The results of this effort are presented in this report.

TABLE OF CONTENTS

FIGURE LIST

FIGURE LIST (cont.)

FIGURE LIST (cont.)

I.

INTRODUCTION

(u) This report describes the objectives and summarizes the progress during the fourth quarter of effort funded under Contract AF 04(611)-10820. This program is being monitored by the Air Force Rocket Propulsion Laboratory, and is being conducted by the Research and Technology Operations of Aerojet-General Corporation. The overall objective of this exploratory development program is to design, develop, and demonstrate a single-chamber controllable solid rocket motor. To accomplish this objective, the technical effort was subdivided into five phases: Preliminary Design, Propellant Tailoring, Heavyweight Motor Development, Lightweight Motor Development and Analytical Studies.

A. PRELIMINARY DESIGN

(u) The purpose of this phase is to establish a base line for program definition. The major efforts in this phase consist of (1) review current technology, (2) conduct tradeoff studies, and (3) formulate a preliminary design of a lightweight controllable solid rocket motor.

B. PROPELLANT TAILORING

(c) The purpose of this phase is to tailor an existing propellant formulation to improve termination ability by L* and P-dot at all back pressures, increase the specific impulse to a design goal of 240 sec at standard conditions, and to characterize the final propellant with respect to extinguishability, ballistic, ignitability, mechanical properties, safety, and processing behavior.

C. HEAVYWEIGHT MOTOR DEVELOPMENT

(u) The objective of this phase is to develop the critical motor components by design, analysis, fabrication, and testing of conservative designs to develop the technology necessary to design the lightweight motor. Included in this technical effort is a subscale motor design and test program, the purpose of which is to evaluate the various materials for restart use in a pintle nozzle design. Six subscale and three fullscale motors are planned in this effort.

D. LIGHTWEIGHT MOTOR DEVELOPMENT

(c) The objective of this phase is the development of a lightweight single-chamber controllable solid rocket motor. This motor has a design goal of a mass fraction of 0.80, must be capable of six thrusting periods with the length and dwell time between periods of thrusting fully controllable by the operator, must be capable of a minimum of 3:1 variation in thrust magnitude, and must be operable at any back pressure from sea level to hard vacuum. Six full-scale lightweight motors will be tested to develop this motor system, and two full-scale

altitude configuration motors will be delivered to the Air Force at Arnold Engineering Development Center for demonstration testing at simulated altitude.

E. ANALYTICAL STUDIES

(u) The objective of this phase is to investigate the effects on internal ballistic properties, mechanical and thermal structures, and general characteristics of a single-chamber controllable solid rocket motor, as this motor design is scaled up and down or reconfigured. The transient and steady-state parameters will be investigated by computer programs generated for this purpose.

II.

SUMMARY

(u) The results of progress made during the fourth quarter under Contract AF 04(611)-10820 are presented. As shown in Figure 1, the effort during this fourth - three month period has been concentrated in the areas of heavyweight motor development and lightweight motor design. Previous work on this contract, including preliminary design, propellant tailoring, subscale motor design and testing, and a portion of the heavyweight motor development has been completed and is reported in the first three quarterly reports, AFRPL-TR-65-204, AFRPL-TR-66-12, and AFRPL-TR-66-99, respectively.

A. HEAVYWEIGHT MOTOR DEVELOPMENT

(c) During this report period, the third and final heavyweight motor was assembled and test fired at altitude. The objective of this firing was stop-restart evaluation and material performance when subjected to refiring at altitude. The motor's thrust was controlled by the pressure feedback control system set for a nominal chamber pressure of 550 psia. Each firing was set for a five second thrusting period prior to an extinguishment command by P-dot. The first firing of HW-3 progressed as planned with complete extinguishment attained as programmed after the five seconds burn. There was no visible damage to any of the hardware. The motor was re-leak checked to verify pressure integrity and fired a second time using the same input program. For the first five seconds, this firing was a duplication of the first test, however this motor did not completely extinguish. Burning continued until web burnout. The motor hardware experienced considerable damage from external heating and caused some damage to the facility. Lack of extinguishment was probably due to backpressure buildup in the diffuser when the trap-door was closed during motor venting, and subsequent unchoking of the nozzle. Considering the severe external heating environment to which this nozzle was subjected, the hardware was in remarkably good condition.

B. SPECIAL TEST EQUIPMENT

(u) On the basis of the test firing of motor HW-3, it was determined that the diffuser entrance required some redesign to change the straight tube entrance to a bell-mouth and increase the clearance between the nozzle and the diffuser. This change is being made to eliminate the possibility of backpressure buildup and subsequent unchoking of the nozzle.

(u) The final console assembly of the pressure feedback control system was completed. This unit is currently being tuned to the response levels consistent with the lightweight motor ballistic parameters and will be available for use throughout the lightweight motor development program including the delivery motors.

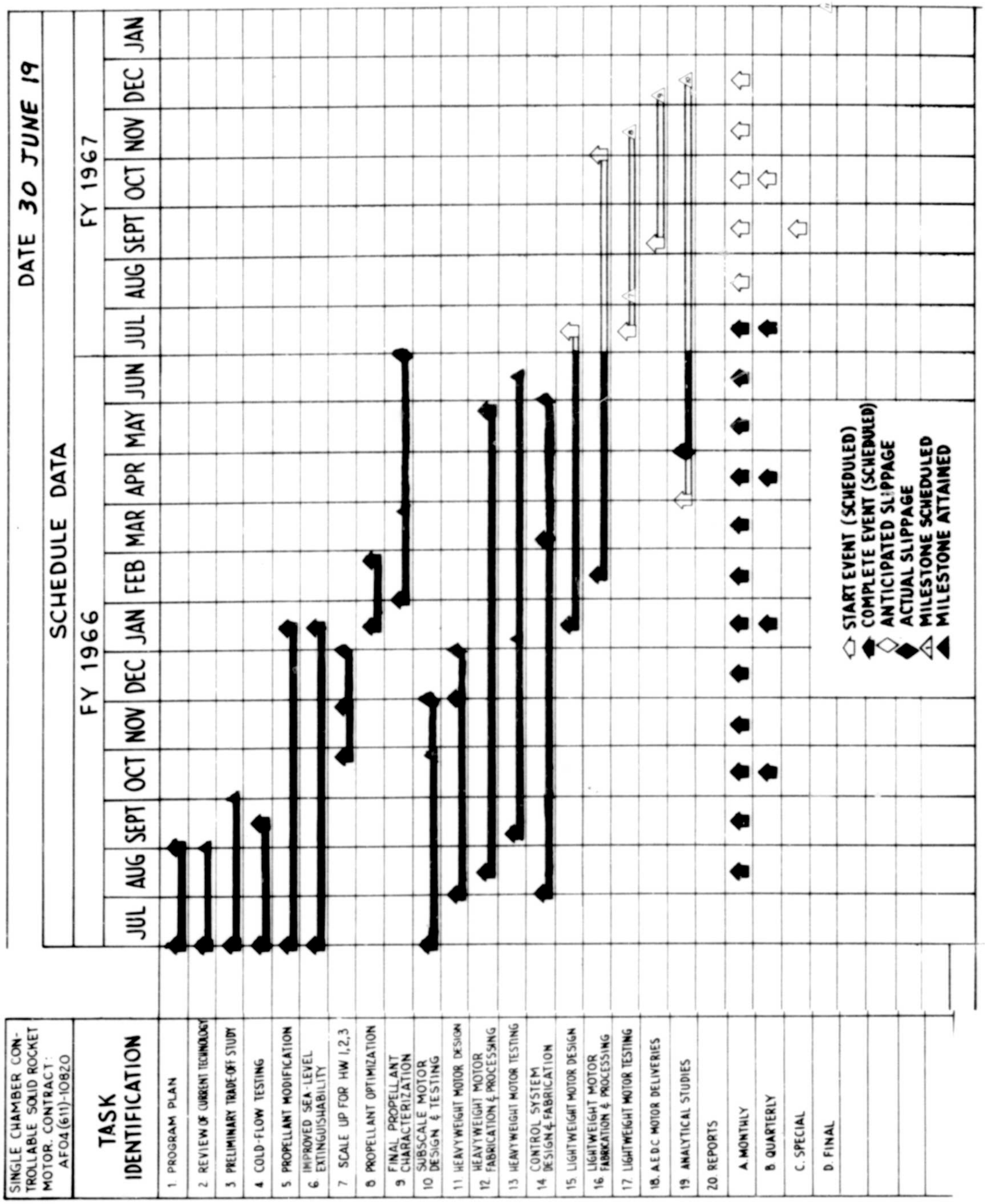


Figure 1. Program Bar Chart

II, Summary (cont.)

C. PROPELLANT RE-EVALUATION

(c) A program to re-evaluate propellants for use in the controllable solid rocket (CSR) was initiated as a result of the discrepancy between the predicted burning rate of propellant AAB-3220 at low pressures and that experienced in the full scale motors. The purpose of this program is to determine the cause of the discrepancy, correct the problem, and to determine whether or not a substitute propellant would better fit the requirements of the CSR. To date, this program has found two propellants which appear to have the characteristics needed by the current design of the CSR motor, are more extinguishable than AAB-3220, and have the specific impulse and oxygen balance consistent with AAB-3220. The burning rate problem has been explained in part by excessive heat loss to the chamber side walls and nozzle in the small 3KS500 burning rate determination motor.

III.

TECHNICAL DISCUSSION

A. HEAVYWEIGHT MOTOR HW-3

(u) During the fourth quarter of technical effort under Contract AF 04(611)-10820, the final heavyweight motor HW-3 was assembled and tested. This motor was equipped with the propellant filled case that has originally been processed for HW-2 but was replaced when a series of voids were found in the R-3 propellant filled case that had originally been scheduled for HW-3. X-ray inspection of this R-2 case indicated that it could be used as it was, therefore the repaired case was fired during the third quarter on motor HW-2 and the R-2 case was used for motor HW-3 without a grain repair.

1. Design

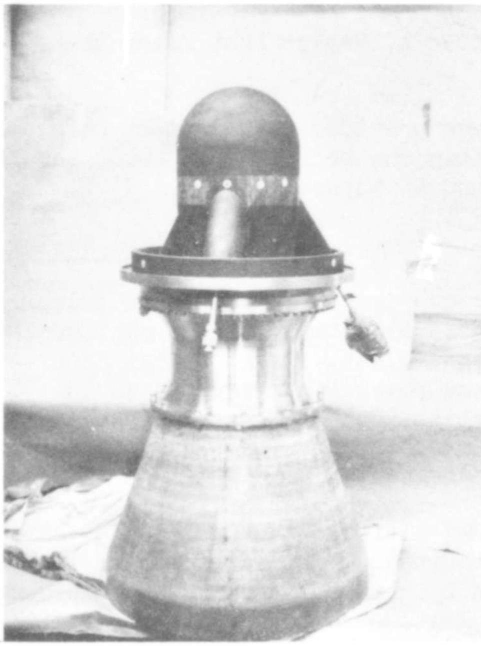
(c) The motor configuration for HW-3 consists of a 20-in.-dia. cylindrical case, cast with a "Finocil" grain configuration of AAB-3220 extinguishable propellant and equipped with six cannister igniters of conventional design and a movable pintle nozzle, with altitude extension cone, for thrust variability and extinguishment. This motor contained approximately 560 pounds of propellant in the main grain and 1.5 pounds of propellant in the first live igniter. All subsequent igniters had a live charge of approximately 3 pounds of propellant.

(u) To eliminate the problem of cutting the teflon capseals used to provide 5000 psi seal capability between the two hydraulic channels in the actuator-manifold assembly, these capseals were removed for motor HW-3 and the system hydraulic pressure was held to a maximum of 3500 psi. On both previous tests, HW-1 and HW-2, the capseals were cut during installation and the small pieces of seal tended to clog the servo valve.

(u) The nozzle assembly used on this motor was very similar to those used on HW-1 and HW-2 with the exception that this nozzle had an altitude extension cone added to increase the geometric expansion ratio from the 10:1 sea level nozzle to a 40:1 altitude nozzle. Four views of this nozzle assembly are shown on Figure 2 prior to the test firings. The altitude extension cone was fabricated from silica-phenolic tape wrapped parallel to the nozzle centerline, with a steel flange bonded and pinned to the cone using silica pins, and with a glass-epoxy cloth layup over the outside of the cone for added strength and flange retention capability. The remainder of the nozzle is the same as that pictured as Figure 64 in the Second Quarterly Report, AFRPL-TR-66-12. The individual components of the nozzle are the same as those presented in the Third Quarterly Report, AFRPL-TR-66-99 as Figures 2 through 7, inclusive.

(u) To protect the motor from diffuser blowback during firing and especially during diffuser unloading after motor extinguishment the aft end of the motor was coated with a trowellable silicon rubber compound and the motor

a. HW-3 Nozzle - Prefire



b. HW-3 Nozzle - Prefire

c. HW-3 Nozzle - Prefire

d. HW-3 Nozzle - Prefire

Figure 2. Nozzle Assembly, HW-3, Prefire

was provided with a blast baffle mounted to the diffuser and the floor rather than the motor. This motor insulation and baffle can be seen on Figures 3, 4, and 5 respectively.

2. HW-3 Test Firing CSR-DA-01S-AH-003

(u) The primary objective of motor HW-3 test firing was to determine the altitude extinguishment capability of the full-scale heavyweight controllable solid rocket motor. As had been shown in the firing of HW-1, it was possible to extinguish the CSR motor at sea level, however with the configuration tested it was impossible to maintain permanent extinction. HW-3 was scheduled for the first simulated altitude test of a full-scale CSR motor of the same configuration as HW-1 to determine the effect of altitude on the ability of the motor to attain permanent extinction. This motor was therefore setup in the W-7 altitude tank at Aerojet's Sacramento Solid Test Facility. This facility was equipped with a diffuser designed for the CSR at mid-mass flow configuration. A hydraulically operated trap-door was provided at the diffuser outlet so that altitude could be maintained after motor shut down to prevent reignition. In addition to the diffuser and trap-door, the altitude facility was equipped with a nitrogen ejector capable of handling 5 pounds/second gas flow at a backpressure of approximately 1 psia. This ejector system could be remotely isolated from the altitude facility by a hydraulically operated butterfly valve so that the tank could be pumped down using the mechanical vacuum pumps to conserve the supply of nitrogen for the actual run.

(c) The CSR motor, HW-3, was scheduled for a total of four thrusting periods, each to be terminated using the rapid depressurization mode of extinguishment. To match the motor output to the diffuser design, it was decided to fire the motor at a chamber pressure of approximately 550 psia. At this pressure, the motor was calculated to flow at approximately 27 pounds/second through an aerodynamic throat area of 7.5 square inches, making the effective expansion ratio approximately 36:1. The exit pressure was calculated to be approximately 1.25 psia, closely matching the tank pressure for which the diffuser was designed. At a mass flow rate of 27 pounds/second, the web duration was calculated to be slightly over 20.8 seconds, thus each pulse was determined to be 5 seconds in duration to permit the four thrusting cycles planned.

(c) Sequencing of the various facility items was a very critical portion of this test. In order of activation the following functions were performed:

(1)	Start Tank Pump-down	T - 2 hours
(2)	Cut in Ejector	T - 20 seconds
(3)	Open Ejector to Tank	T - 15 seconds
(4)	Release Diffuser Trap-door	T - 1 second

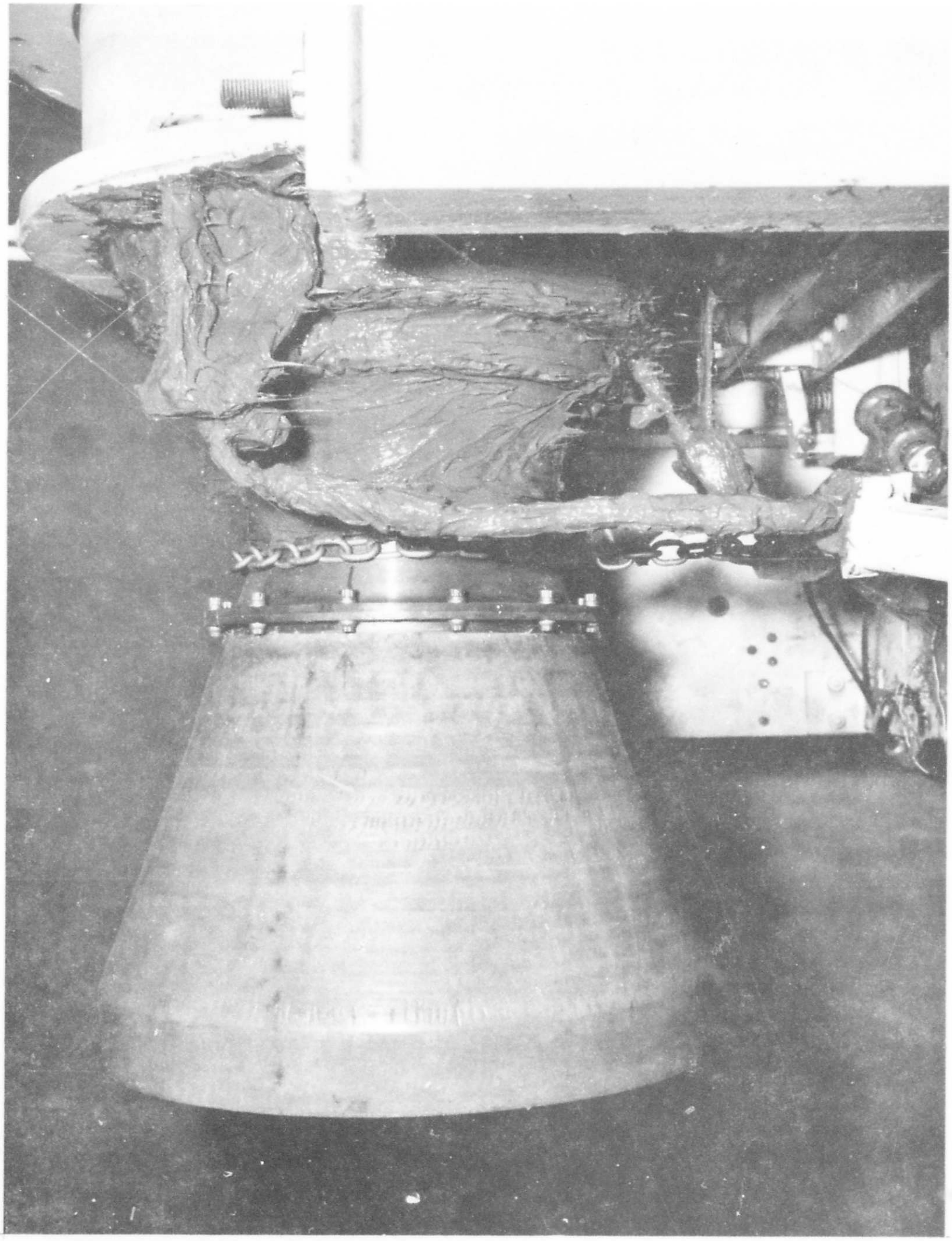


Figure 3. 90% Nozzle, HW-3, Prefire

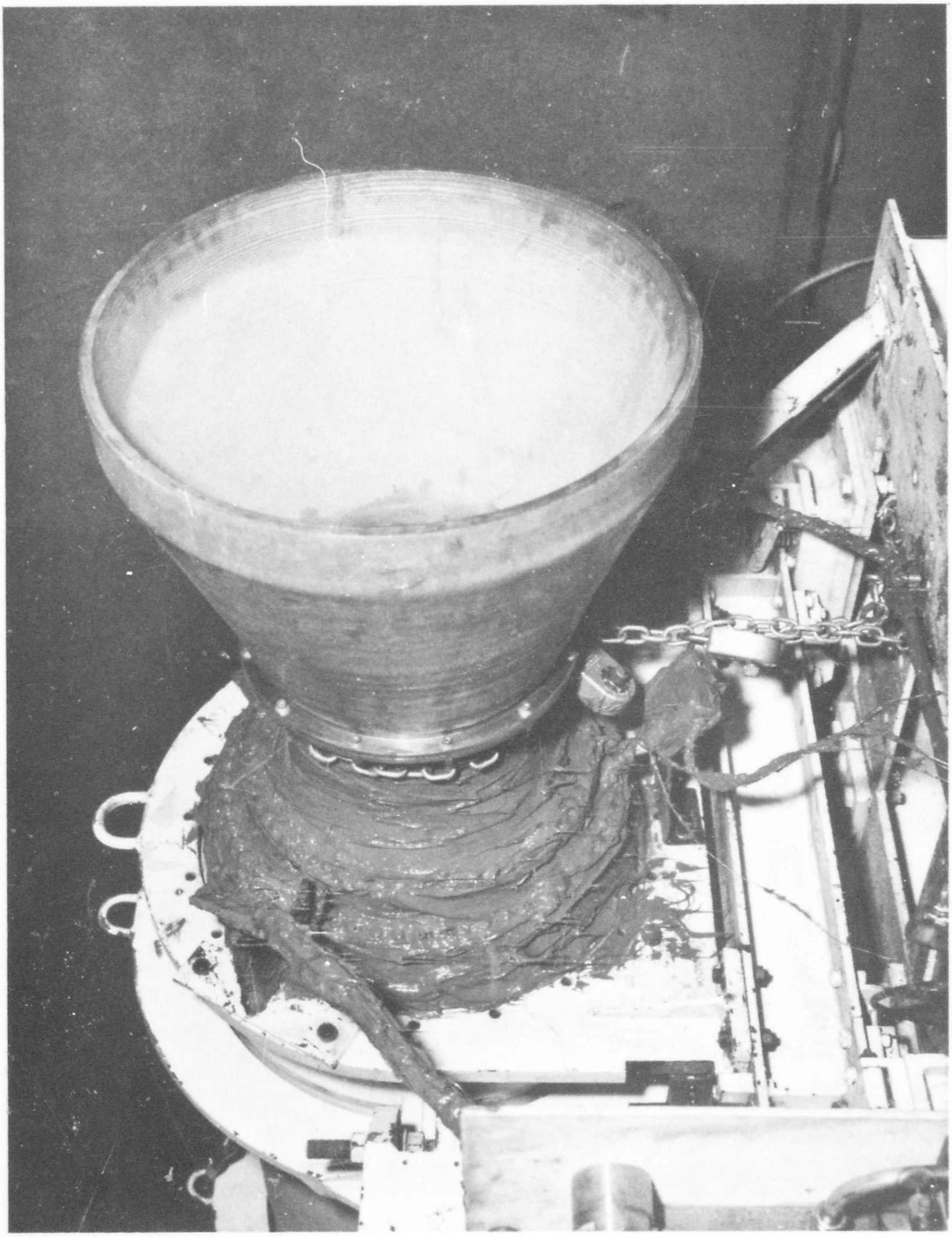


Figure 4. 3/4 Aft Port, HW-3, Prefire

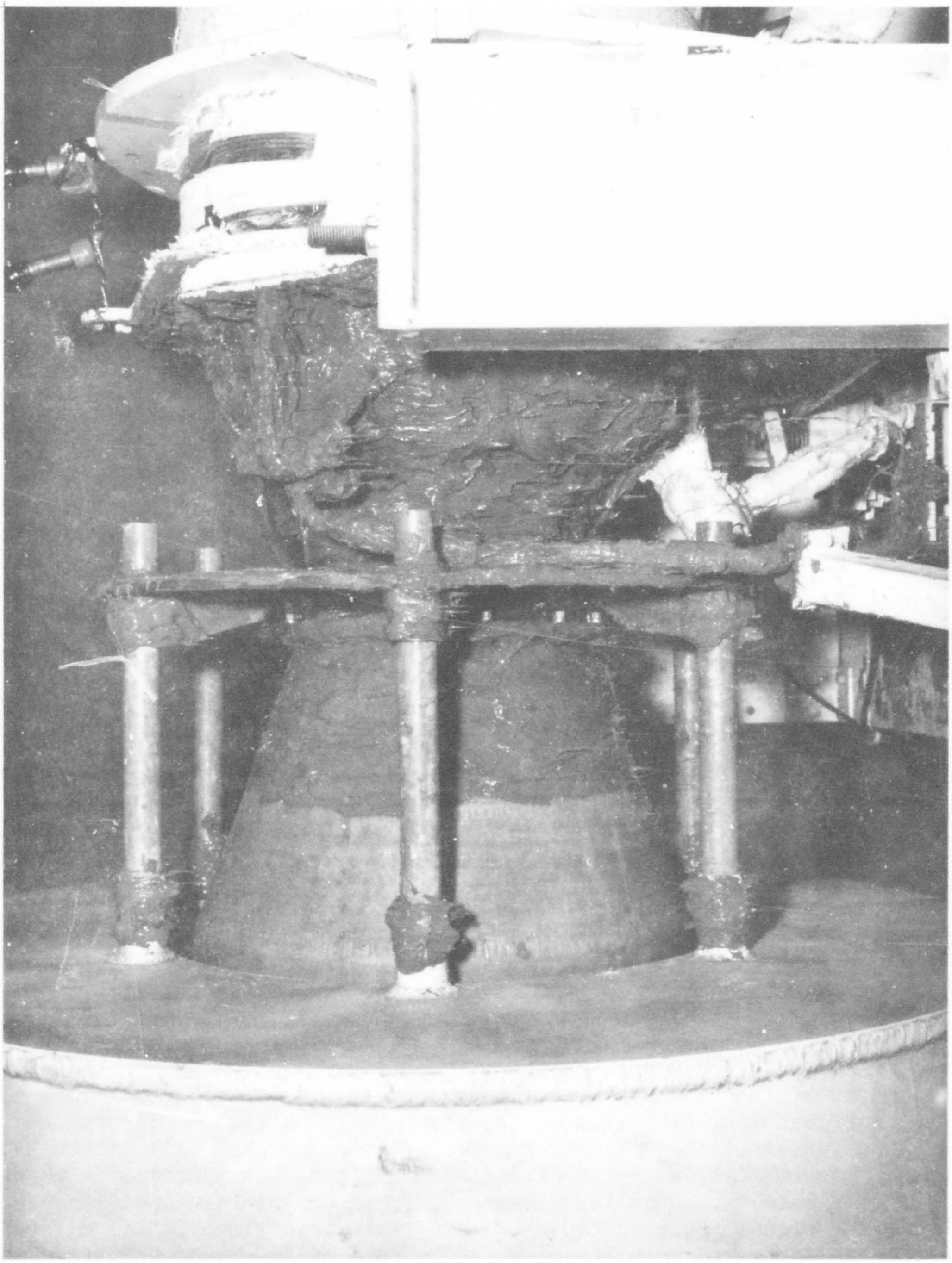


Figure 5. 90% Nozzle, HW-3, Prefire

III, A, Heavyweight Motor HW-3 (cont.)

(5)	Ignition Command to Motor	T - 0 seconds
(6)	Activate Trap-door to Close	T + 4 seconds
(7)	Isolate Ejector from Tank	T + 25 seconds
(8)	Shut-down Ejector Nitrogen	T + 35 seconds
(9)	Vent Tank to Atmosphere	T + 1 hour

The most critical of these functions were numbers (4) and (6) which involved opening and closing the trap-door at the exit end of the diffuser. By releasing the hydraulic pressure holding the door shut at T - 1 second, the door is held in in place by the differential pressure (by the atmosphere) until the motor fires and pushes the door 10 degrees open. At that point the hydraulic actuator is cut in to the circuit and completes the door opening. Dry runs indicated that the trap-door required approximately 1 second to close, thus it was commanded to close at T + 4 seconds, approximately one second before motor shutdown command. This timing was set to avoid if possible the entry of oxygen laden air after motor venting. Vacuum was held for one hour to subject the motor to heat soak prior to allowing convective cooling to take place.

(u) For this firing, the motor was equipped with only one live igniter for each pulsing period rather than the four igniters being installed for each firing. This was necessary since the facility has not as yet been setup to handle more than one exploding bridge wire squib at a time. In addition, some problems have been encountered with the rupture discs in the multiple cannister igniter design being used. These discs are fabricated from light gage nickel alloy and coined to hinge open yet remain retained by the hinge-flap. Due to the high rate of pressure rise in the igniter and the shock loading, the hinge concept is non-functional and the disc is ejected intact. As each disc is slightly larger than the common igniter udder throat passage, damage has been sustained by the throat insert due to the passage of these discs. This area is being redesigned for future altitude test motors to eliminate this problem. For HW-3, it was decided to fire all four igniters down the centerline port of the ignition system without rupture discs to avoid this problem.

(u) To measure the thermal feedback to the motor due to diffuser unloading and backflow during the run, thermocouples were spotwelded to the chamber and heat-flux probes were installed on the blast baffle. The chamber was wrapped with one ply of asbestos cloth to further protect the hardware from external heating. All of the instrumentation lines were wrapped with asbestos as were the thrust and motor weight load cells. Flash bulbs, wired into the ignition circuit, were provided to signal ignition to the camera that was trained on the diffuser entrance through a view port in the side of the tank wall. These features can be seen on Figures 6, 7, 8, and 9.

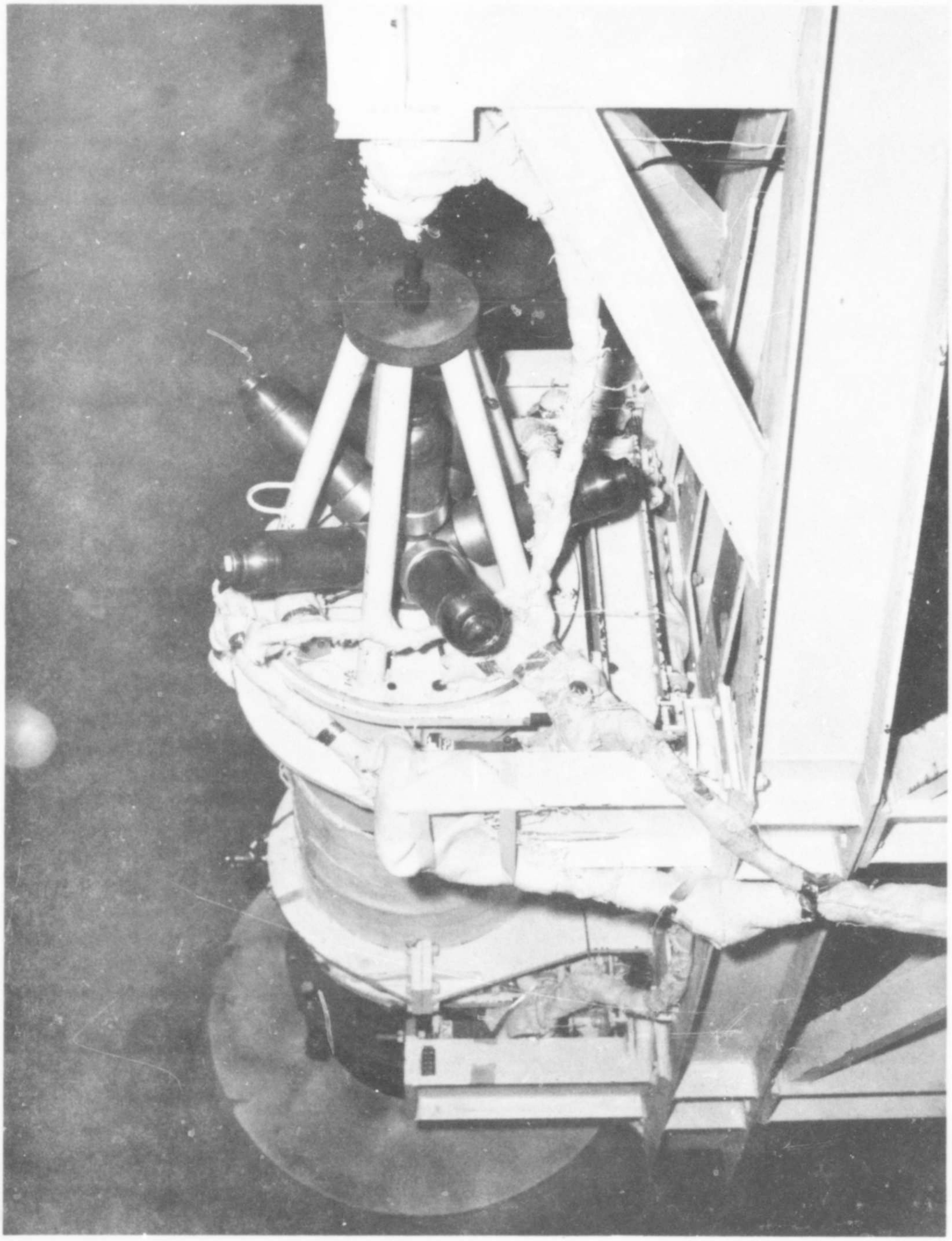


Figure 6. 3/4 Fwd., HW-3, Prefire

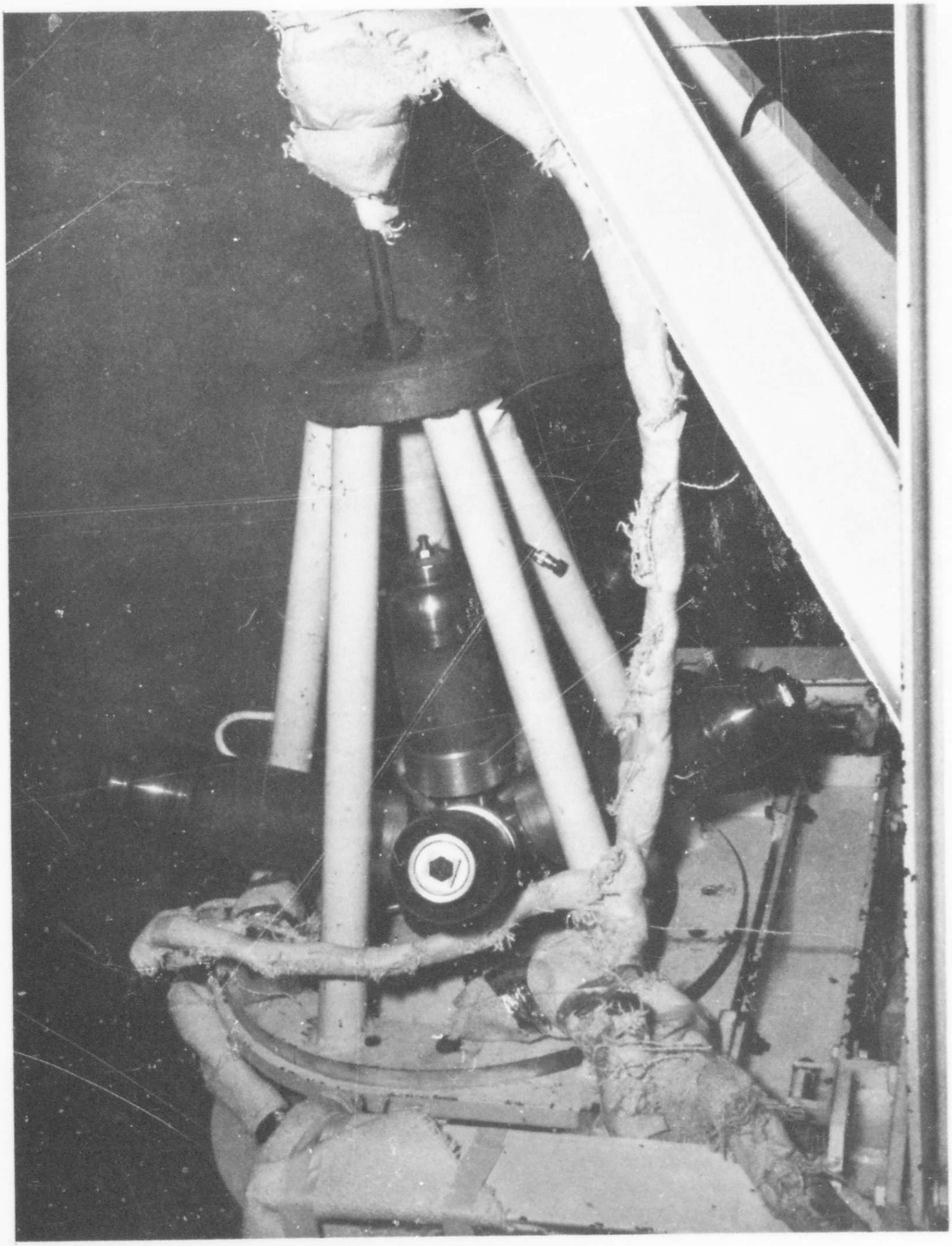


Figure 7. Fwd. Closure, HW-3, Prefire

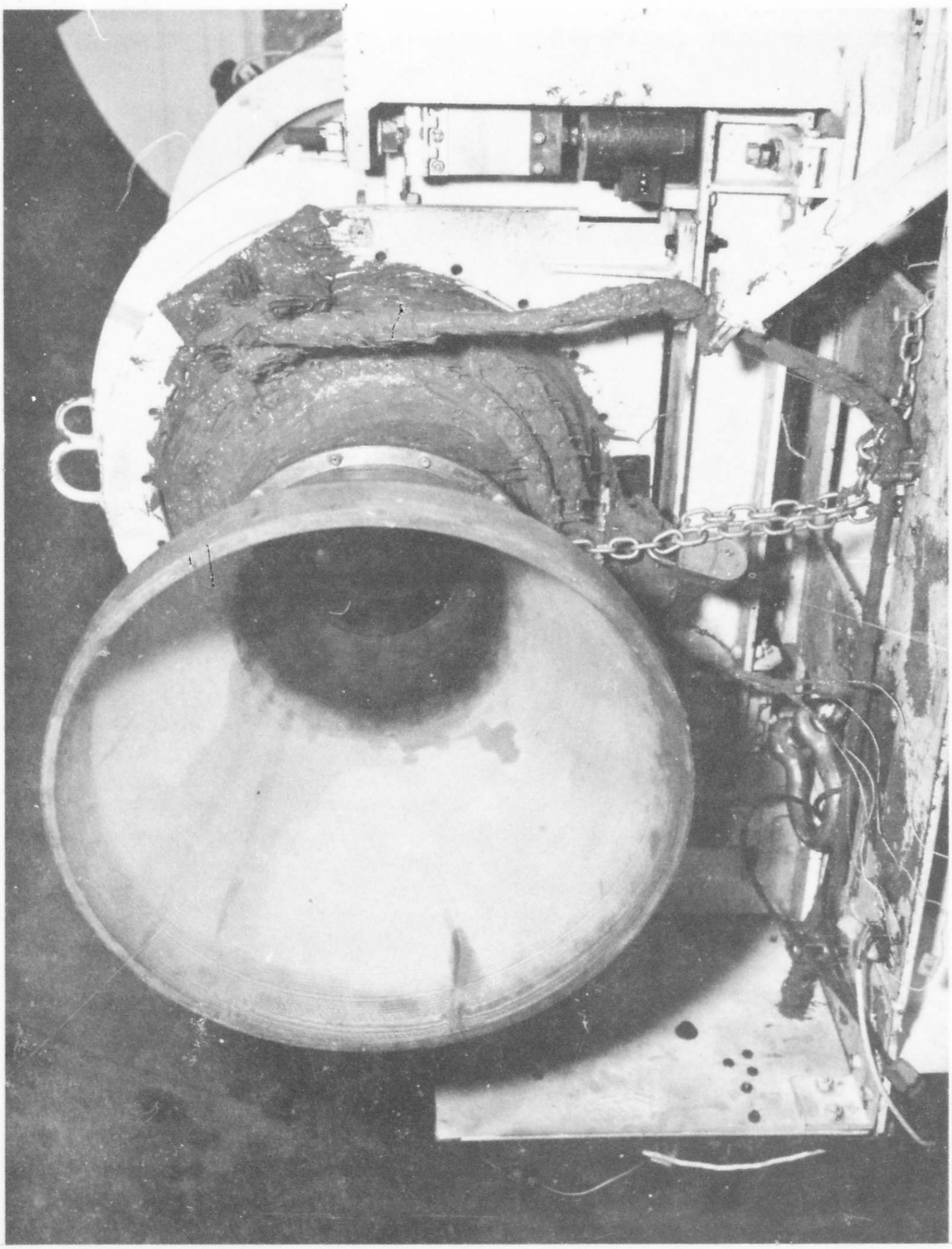


Figure 8. 3/4 Aft STBD, HW-3, Prefire

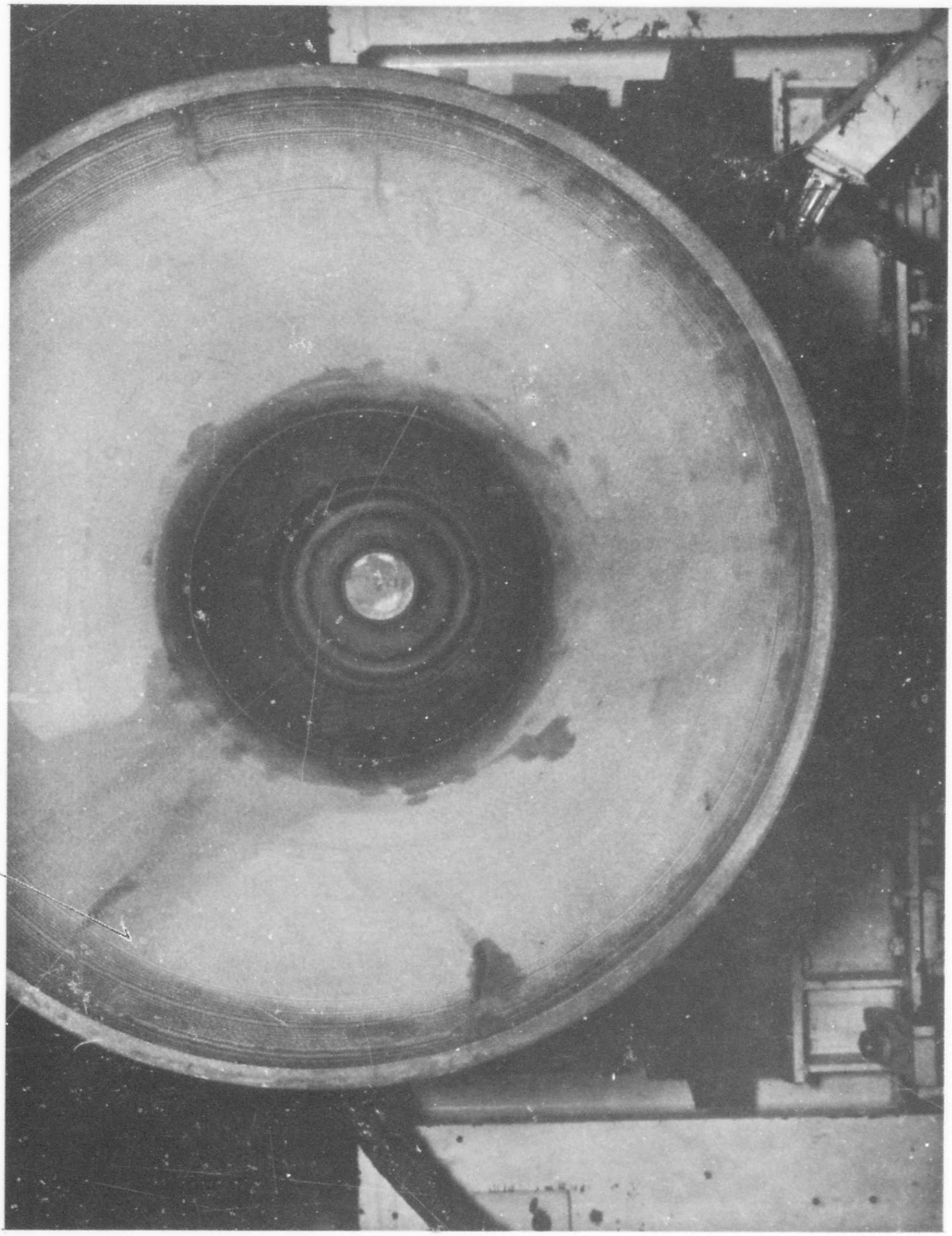


Figure 9. C/V Nozzle, Aft, HW-3, Prefire

(c) Heavyweight Motor, HW-3, was statically test fired at 0315 hours 30 April 1966, in the simulated altitude facility W-7 at Aerojet's Sacramento Solid Test Facility. Ignition was smooth and the firing proceeded as programmed for the five second duration at which time the motor was successfully extinguished by the P-dot technique. Average chamber pressure of 550 psia was commanded and control was maintained, however there was a low frequency oscillation (approximately 1 cps) with a 50 psi amplitude during the five second run. Altitude was maintained for approximately one hour after the test before the tank was opened.

3. Data Analysis HW-3 Run 003

(c) Review of the data from HW-3 Run 003 indicated that ignition was smooth and normal with maximum chamber pressure of 585 psia during the ignition transient being reached at approximately 0.270 seconds, igniter burnout time. The chamber pressure dropped to a low of 490 psia after igniter burnout and before force mode control was initiated at 0.500 seconds. When force mode control was cut in by the timer circuit, the chamber pressure recovered and began the low frequency oscillation previously discussed. With the exception of the first half second, the thrust delivered was smooth and averaged approximately 7600 pounds. At extinguishment command, the thrust spiked to approximately 12,800 pounds before dropping. The Thrust-Time and Pressure-Time plots for this test are presented in Figure 10.

(c) The input to the control system was set at 4100 pounds, a multiple of the chamber pressure times the calculated nozzle throat area. This parameter was measured at the input point to the control computer, however an anomaly in the scale factor made the data non-usable. The input force received was thus calculated from the feedback measurements and the error measurements. This calculated input as a function of time is presented on Figure 11. As this is a calculated parameter rather than a measured parameter and since the first 0.500 seconds and all readings after 5.000 seconds are not indicative of the signals sent to the motor, these readings should be ignored. For the first half second the motor is on a pintle position control mode to allow for ignition and motor stabilization. At the five second point, when P-dot extinguishment is commanded, the control system is bypassed and the fail-safe manifold is activated. The actual feedback signal from which the input was calculated is presented on Figure 12. The same oscillations are present on this plot as were evident on the Thrust-Time and Pressure-Time traces. These oscillations were the result of increased gains in this control system over those used on HW-1 and HW-2 test firings. Due to the slow response of those two motors to input commands it was decided to increase the system gains until minor oscillations occurred in an attempt to keep the motor operating within the capability of the diffuser.

(c) As can be seen from Figure 13, the Thrust/Pressure versus Time trace for HW-3, the minor oscillations are present, however they are out of phase with those of thrust and pressure. This trace is a measure of the nozzle throat area times the nozzle thrust coefficient as a function of time. The low

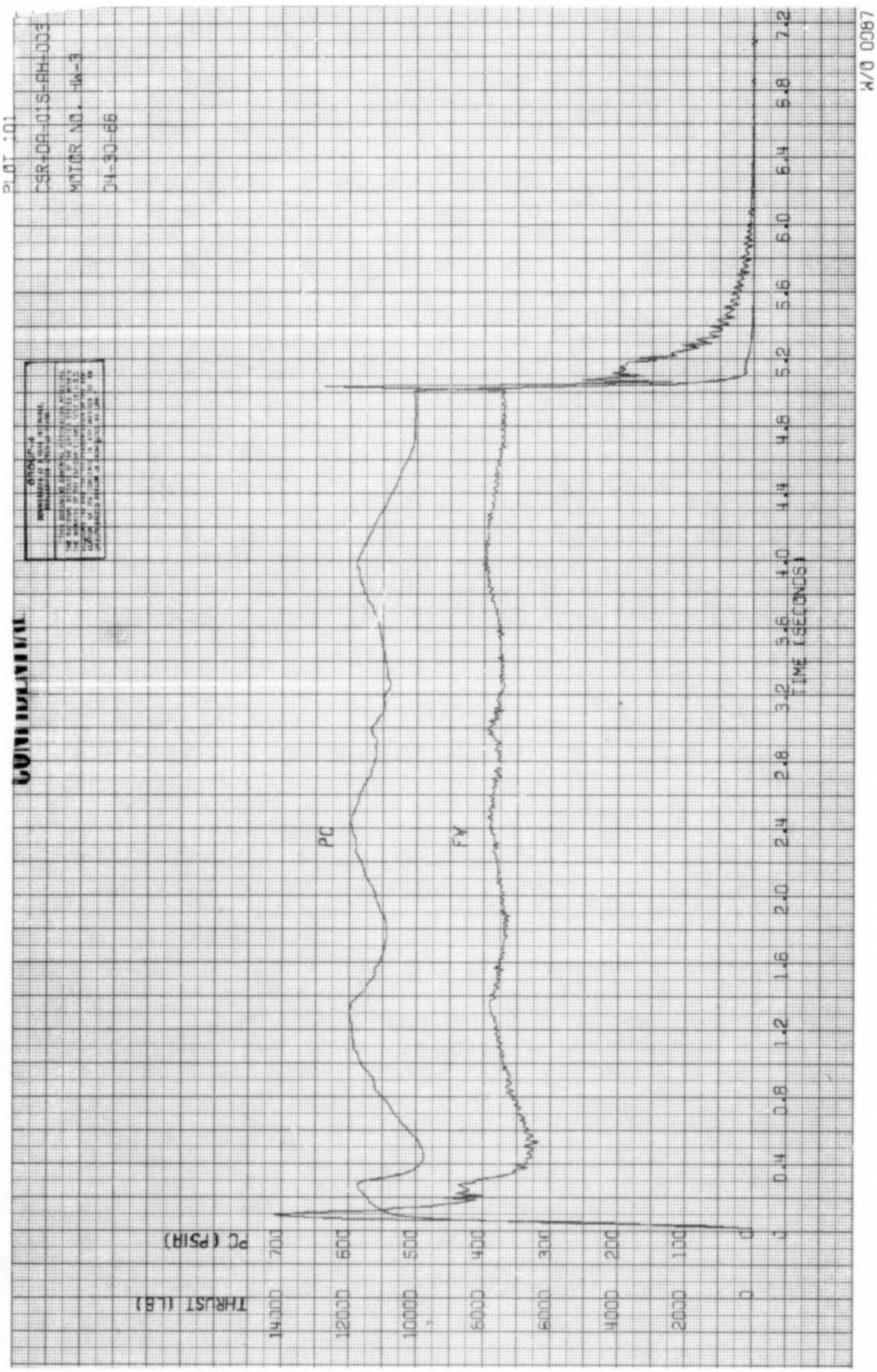


Figure 10. Thrust-Time and Pressure-Time, HW-3, Run 003 (u)

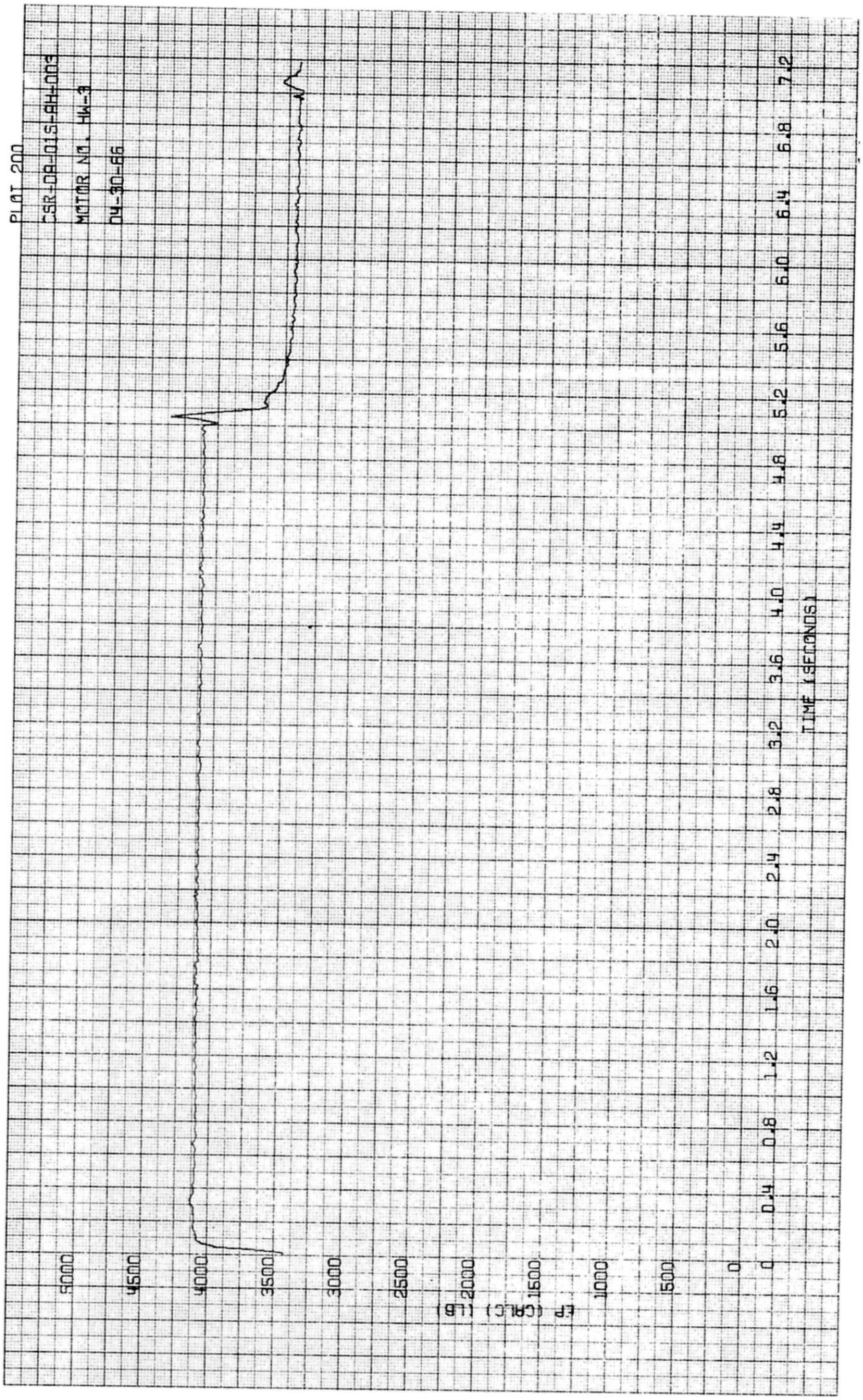


Figure 11. Program Input-Time, HW-3, Run 003

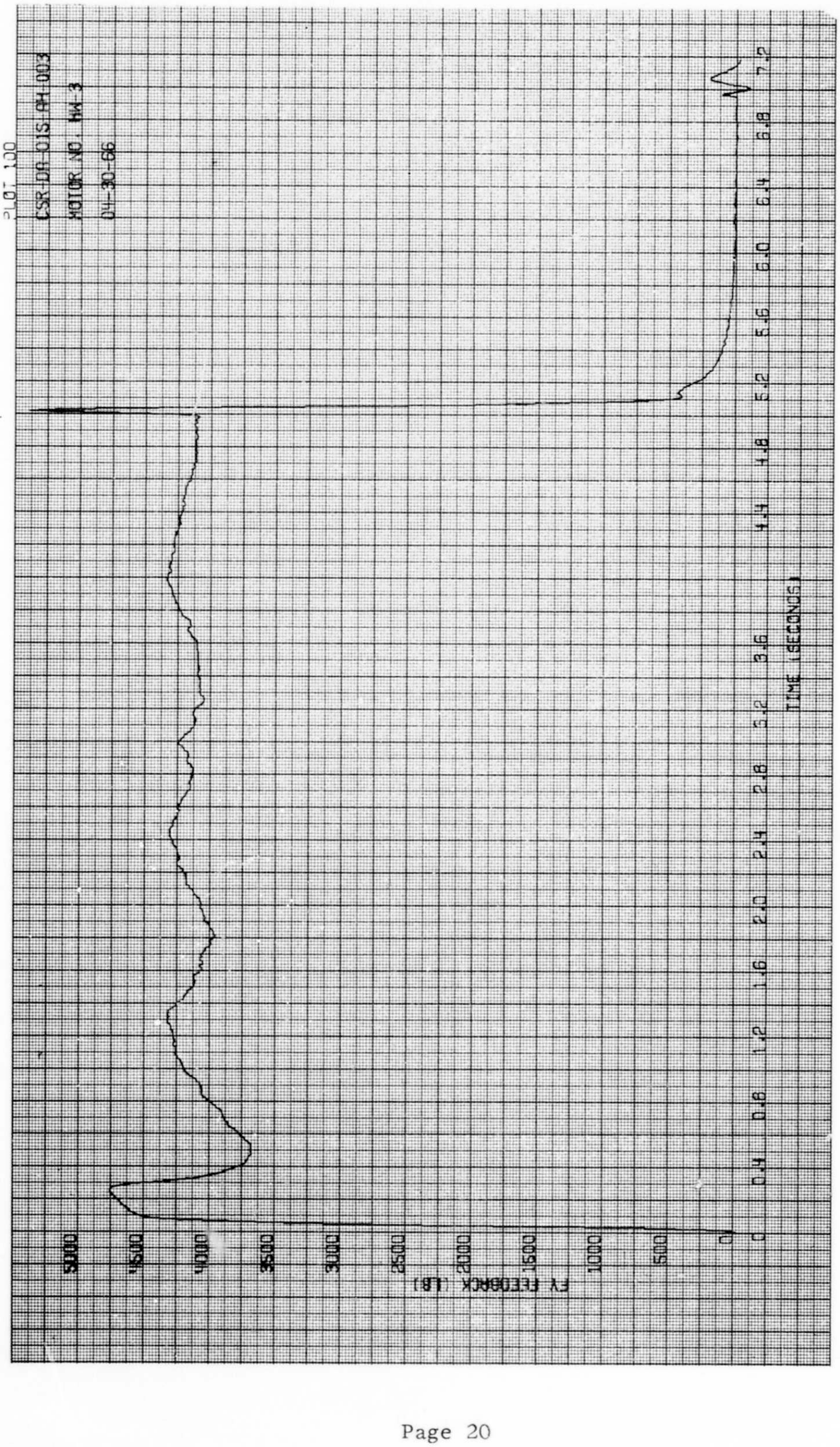


Figure 12. Feedback-Time, HW-3, Run 003

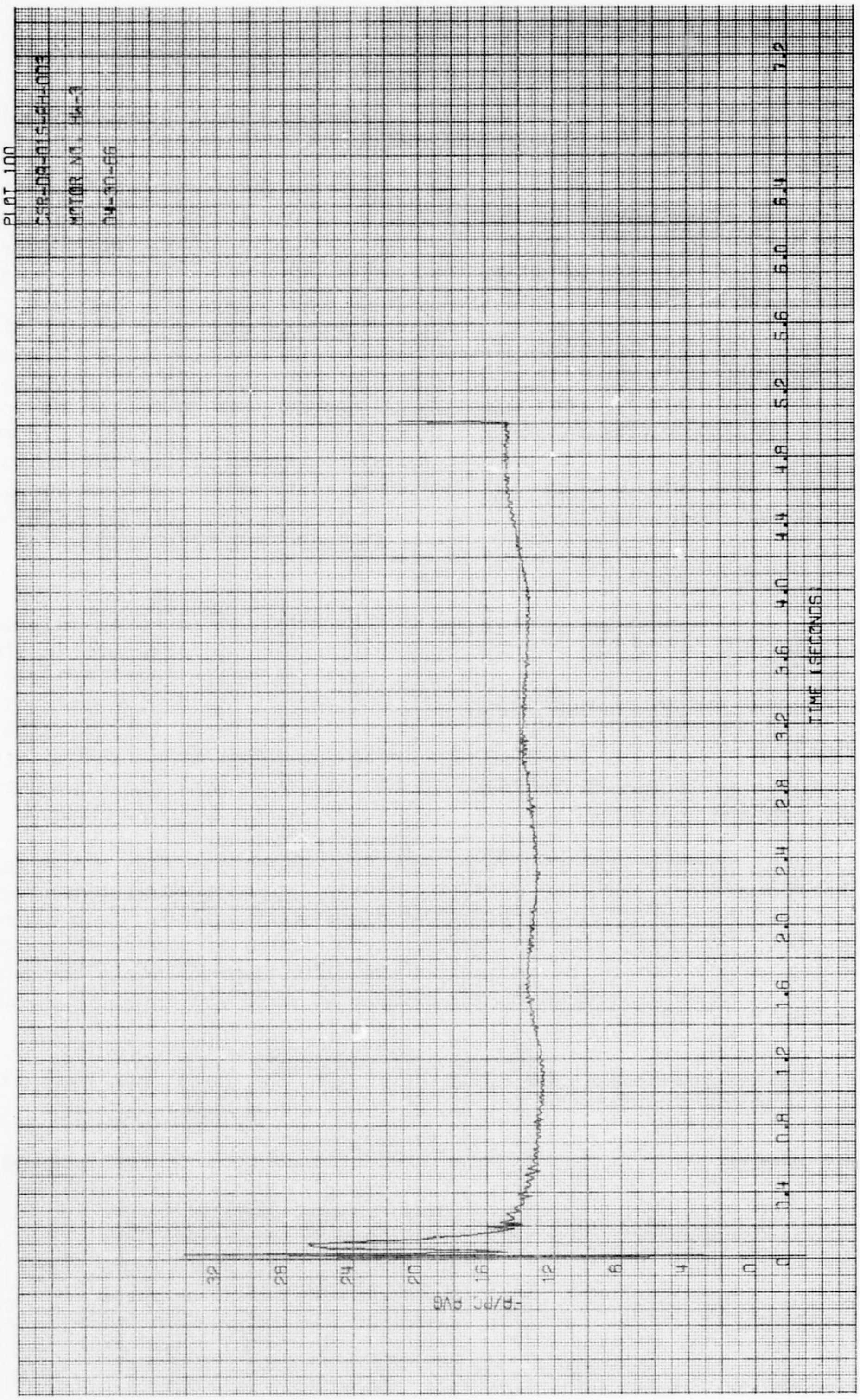


Figure 13. Thrust/Pressure - Time, HW-3, Run 003

III, A, Heavyweight Motor HW-3 (cont.)

amplitude-high frequency oscillations that are superimposed on the general trace are caused by the ringing of the test stand and do not reflect the motion of the pintle.

(c) This motor was test fired on a stand designed to continuously weigh the motor during the test. Four load cells are provided for this function. Figure 14 is a trace of the sum of these load cells subtracted from the initial reading prior to fire-switch. The oscillations on this trace are caused by the ringing of the test stand and in no way reflect the mass flow rate at any time. At the 7+ second point the oscillations are damping out and the apparent weight loss, counting the initial offset of 19 pounds, is approximately 140 pounds. The total motor impulse delivered in the first 5.100 seconds was 38,634 pound-seconds. Dividing this by the 140 pounds an average delivered specific impulse of approximately 272 seconds is derived. The average expansion ratio of the nozzle is 36:1 and the half angle is about 15 degrees. Expansion is close to optimum considering the diffuser pressure, thus correcting this value of specific impulse back to standard sea level, the propellant delivered a standard specific impulse of about 239+ seconds as expected.

(u) The ejector system and diffuser system operated slightly better than designed as at no time during this firing did the pressure in the altitude tank exceed 0.40 psia and for the most part held at a level of 0.16 psia, or an equivalent altitude of approximately 100,000 feet. The design point for this system was 1.0 psia, or slightly over 60,000 feet. The differential pressure between the tank and the atmosphere was recorded and subtracted from the absolute atmospheric pressure. The result, the actual pressure in the altitude tank, is presented on Figure 15 as a function of time.

(u) During the test, the heat flux gages recorded a thermal input to the flame baffle of less than 1.0 BTU/square foot - second. During the venting this value increased to approximately 4.0 BTU/square foot-second. This trace is shown on Figure 16. The total rise in surface temperature of the chamber was somewhat less than ten degrees over the entire test and for approximately two minutes thereafter. The thermocouple traces as a function of time are shown on Figures 17 and 18.

(c) In summary, the analysis of the test data from HW-3 Run 003 indicated that the motor yielded the following performance data:

Duration:	5.100 seconds to diffuser venting
Thrust:	7600 pounds average
	6500 pounds minimum
	8000 pounds maximum
	14,200 pounds ignition spike
	12,800 pounds extinction spike

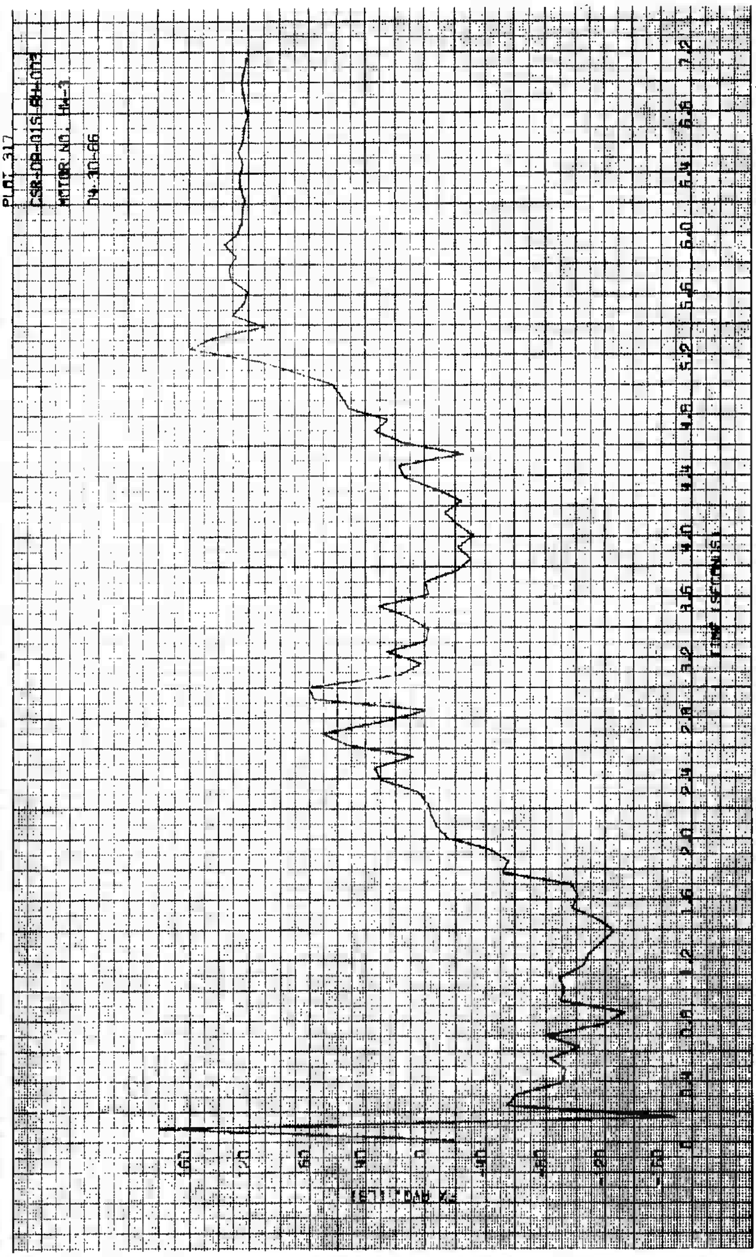


Figure 14. Weight Loss - Time, HW-3, Run 003

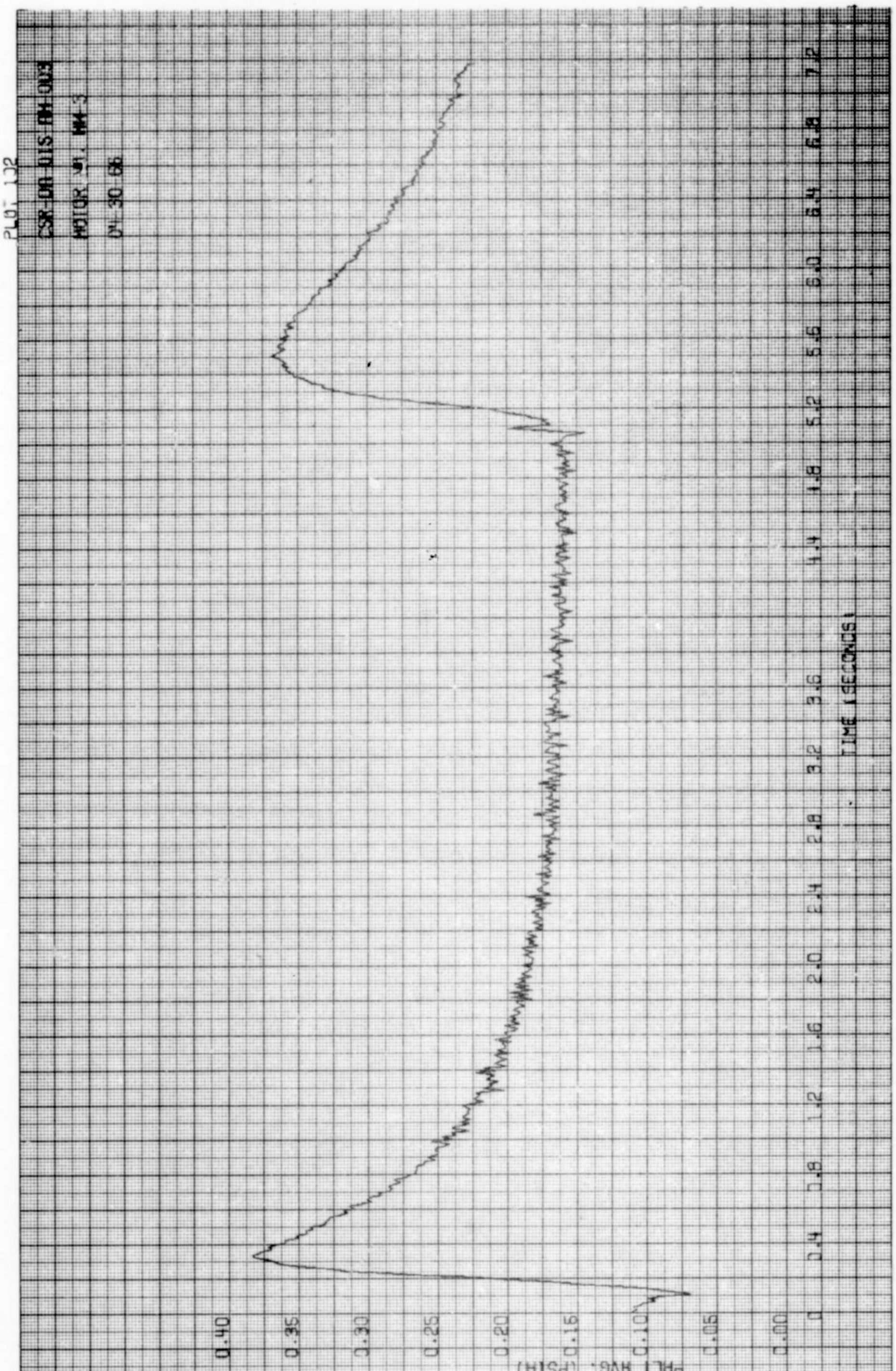


Figure 15. Altitude Tank Pressure - Time, HW-3, Run 003

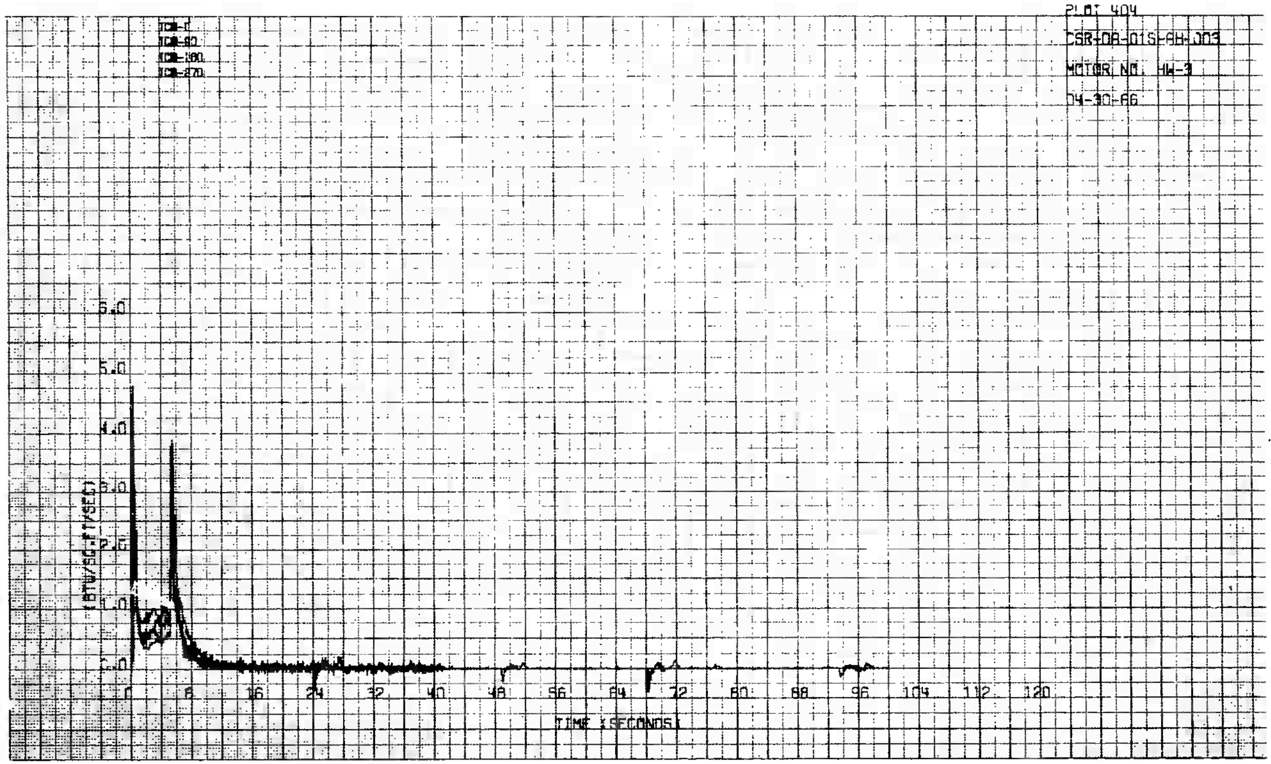


Figure 16. Heat Feedback - Time, HW-3, Run 003

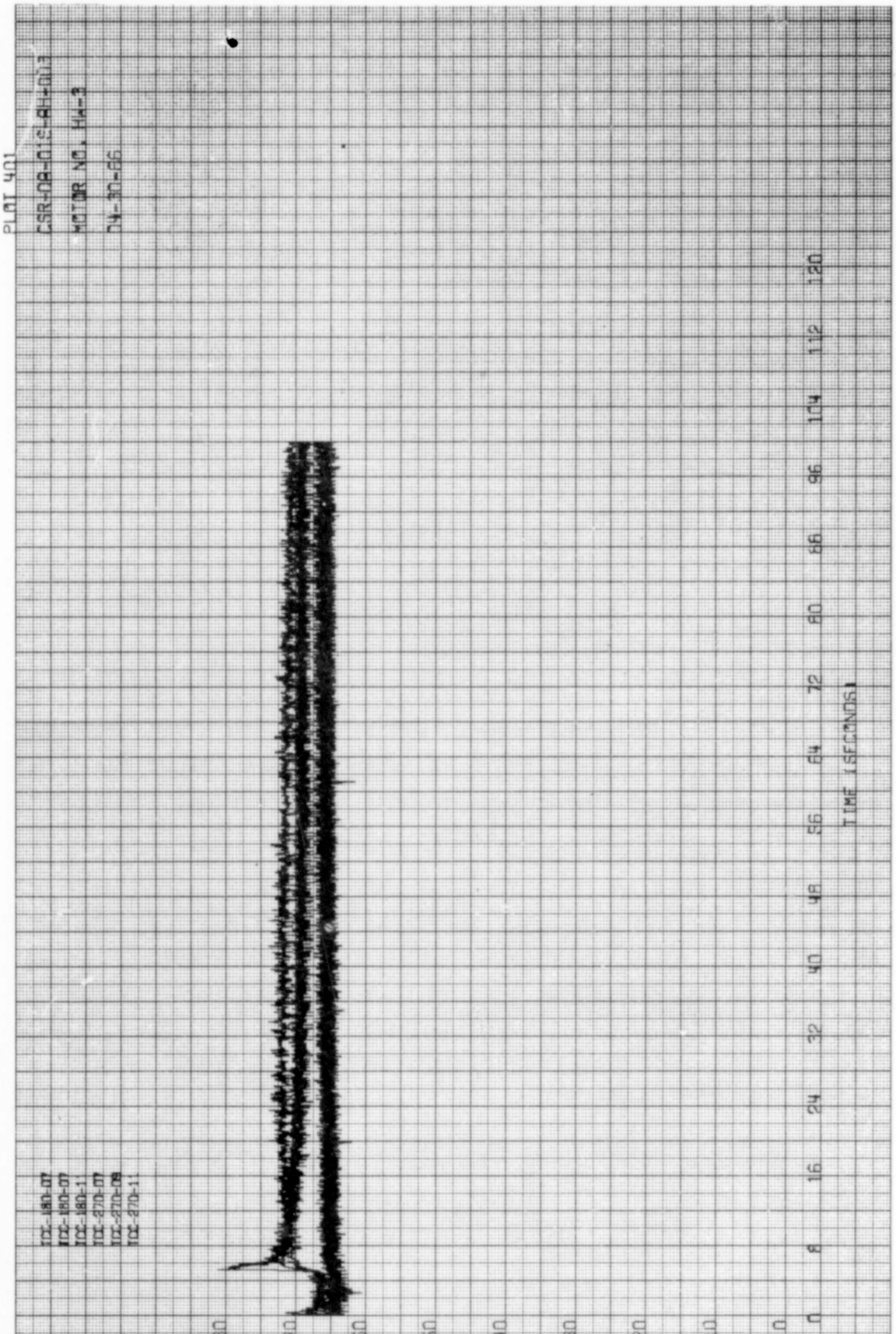


Figure 17. Chamber Thermocouples, HW-3, Run 003

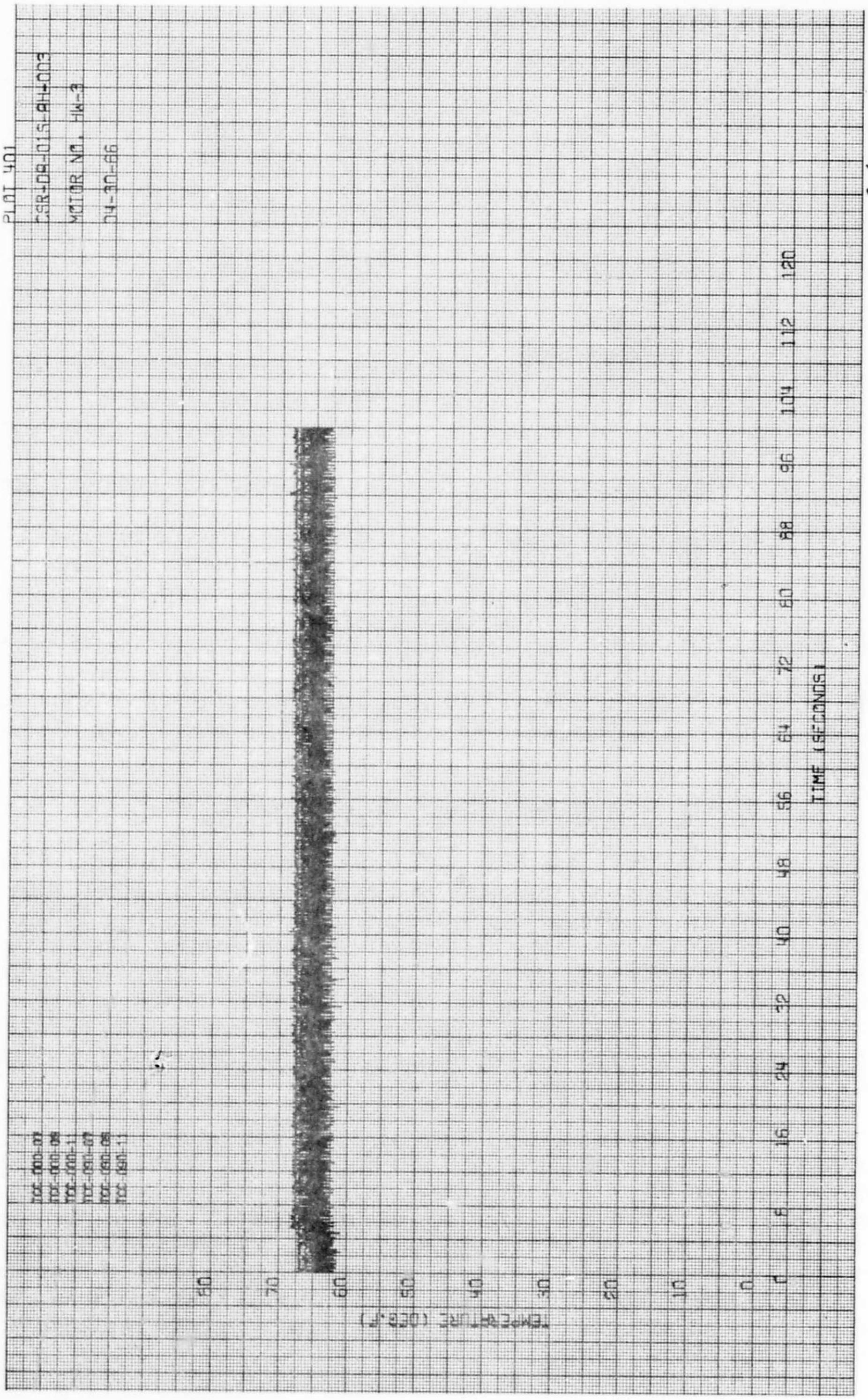


Figure 18. Chamber Thermocouples, HW-3, Run 003

Pressure:	548 psia average 480 psia minimum 600 psia maximum
Weight Loss:	140 pounds
Is Delivered:	272 Lb-sec/lbm
Is Corrected: (SRO conditions)	239+ Lb-sec/lbm
Impulse:	38,634 pound-seconds (Does not include diffuser backflow)
Pressure-Time:	2782 psia-seconds (to 5.10 sec)
Nozzle Throat Area:	7.50 square-inches average 7.35 square-inches minimum 7.95 square-inches maximum

The corrected specific impulse was determined from the thrust coefficient corrected to optimum expansion ratio at a 15-degree half angle from 1000 psi to atmospheric pressure. The nozzle throat area was determined from back calculation using the thrust divided by the chamber pressure and is based upon a variable thrust coefficient.

4. Postfire Hardware Evaluation HW-3 Run 003

(u) As this was only the first firing of a scheduled four firing series on this motor, the motor hardware was not disassembled after this test. Two views of the motor after this first test are shown on Figures 19 and 20. In general, the motor was in excellent condition after this first test with very little evidence of thermal degradation on any of the components. The only evidence that the motor had been subjected to a firing was on the exterior of the nozzle exit cone extension where the glass overlay had been pealed back during the diffuser unloading. Only the glass cloth was affected, the silica phenolic liner being in excellent condition.

(u) This being the first altitude firing and heat soak that the full scale CSR motor had experienced, it was decided not to risk a subsequent failure on the leakage of an O-ring. The nozzle exit cone extension was therefore removed and the remainder of the motor repressure-checked. The major worry was the single Viton-A O-ring that seals between the outside diameter of the pintle piston and the strutted housing. This O-ring is subject to full chamber pressure with the backside of the O-ring vented through the struts to the tank pressure. All seals were found to be sound and the nozzle exit cone extension was replaced to make the motor ready for the second firing.

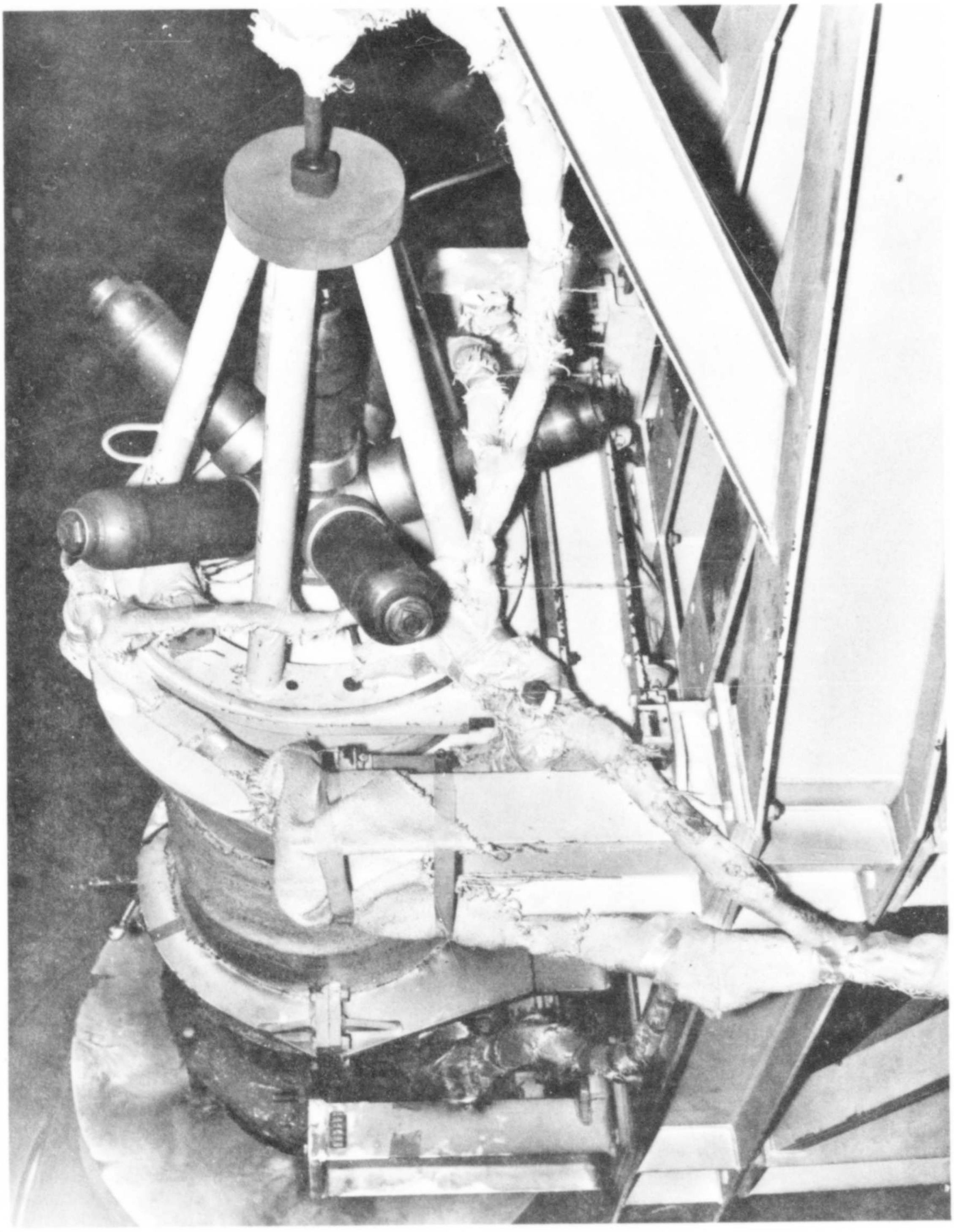


Figure 19. Overall Motor, HW-3, Run 003, Postfire

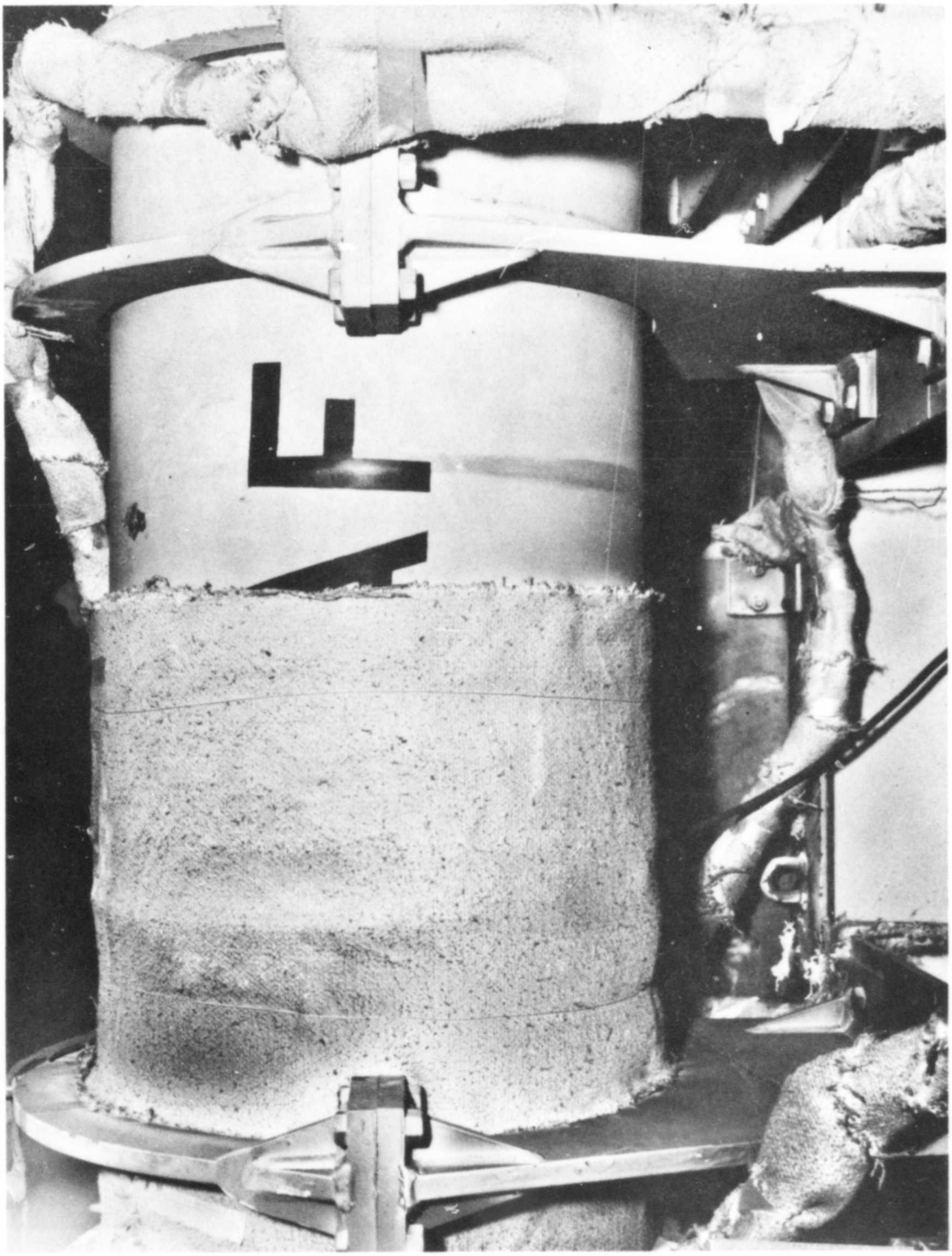


Figure 20. Chamber, HW-3, Run 003, Postfire

(u) As the motor was being repositioned in the altitude facility and made ready for the second test, pintle position was rechecked and found to be in the same relative electrical and mechanical position as it was prior to the first firing, indicating that the linear potentiometer in the pintle actuator assembly had not experienced any noticeable temperature rise.

5. Conclusions

(c) On the basis of this first altitude test firing of the controllable solid rocket motor and the successful extinguishment of the propellant grain using the P-dot technique, it was shown that large motors (600 pound live grain) can be made and controlled as readily as the small motors (100 pound live grain) that were tested under the P-dot and L* extinguishment contracts concluded in 1965, contracts AF 04(611)-9889 and AF 04(611)-9962, respectively. The motor performed as predicted and the control system maintained good control of the motor output even though the gains were set slightly too high for optimum control. From the results of this firing, there was no reason to believe that this motor could not be refired and extinguished successfully for the six thrusting periods that it had been designed. The one potential problem area that had been a source of worry prior to the test, namely the unloading of the gases trapped in the diffuser when the trap-door was closed during the extinguishment transient, appeared to cause no problems whatsoever during the actual test.

6. HW-3 Refiring CSR-DA-01S-AH-004

(u) The only repairs made to HW-3 after the first test were those dealing with the external insulation in the area of the baffle and the exit cone. Both the blast baffle and the exit cone were reinsulated with the trowellable silicon rubber compound as is shown on Figure 21. It should be noted in this figure that the clearance between the nozzle exit cone and the diffuser entry appear to be almost closed due to the trowellable insulation on the exit cone extension. This clearance, when compared with that of the first test of this motor as shown on Figure 5 apparently played a very important part in the outcome of HW-3 Run 004 as will be discussed later.

(u) On the forward end of the motor, the fired igniter that had been located in the boss on the motor centerline was removed and replaced with a large unfired igniter to avoid the problem of rupture disc ejection and subsequent igniter throat damage as was previously described. The new igniter is shown as installed on Figure 22 prior to the second test of motor HW-3.

(c) Motor HW-3 was fired for the second time at approximately 2305 hours also on 30 April 1966. This motor was programmed the same as the first test of this motor in an attempt to duplicate the data with the larger motor free volume present after the second pulsing period. Ignition was smooth and normal and the firing was without major incident until extinguishment was commanded at T+ 5 seconds. Extinction did not occur, the trap-door closed on schedule, the door

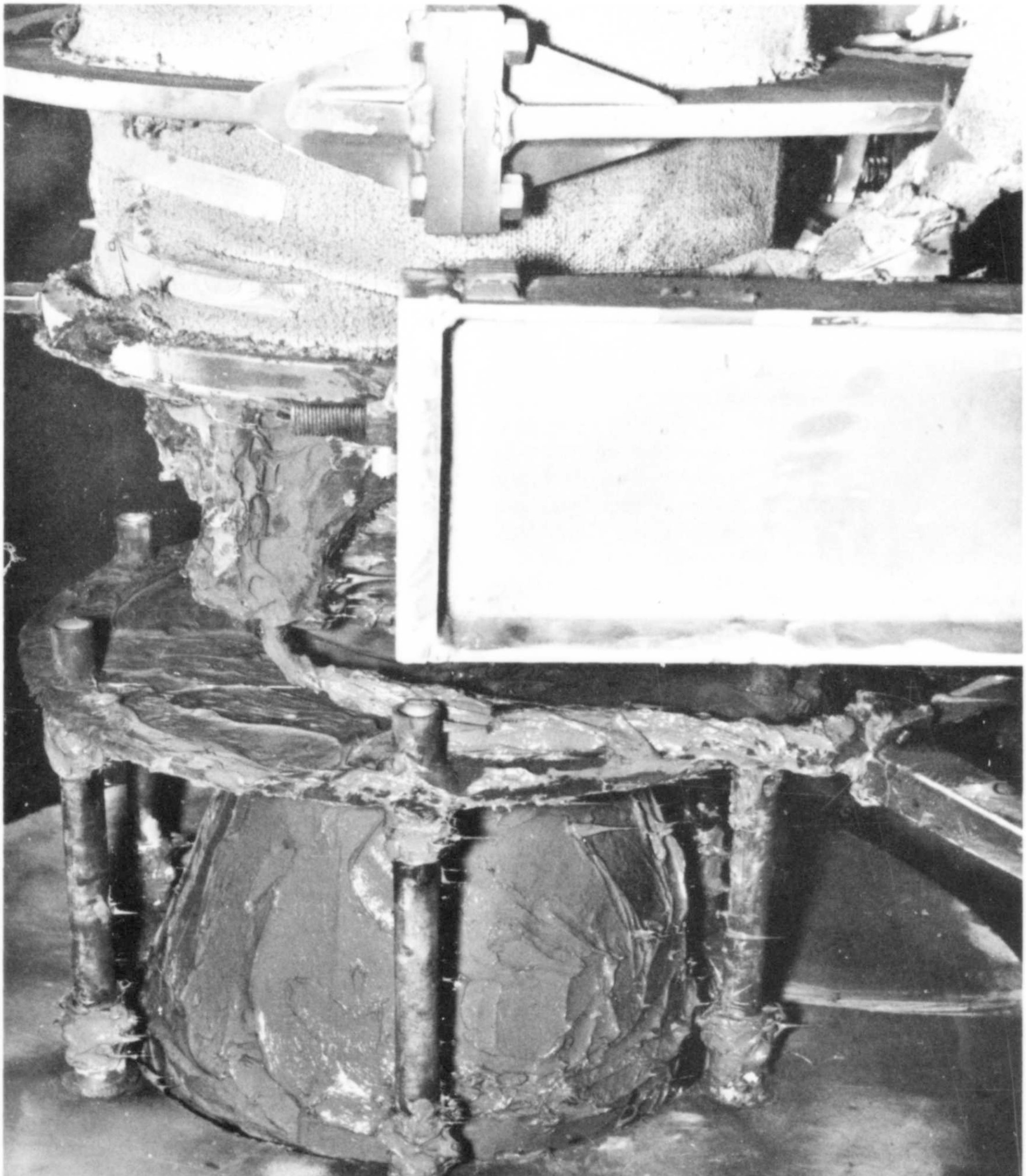


Figure 21. Aft View, HW-3, Run 004, Prefire

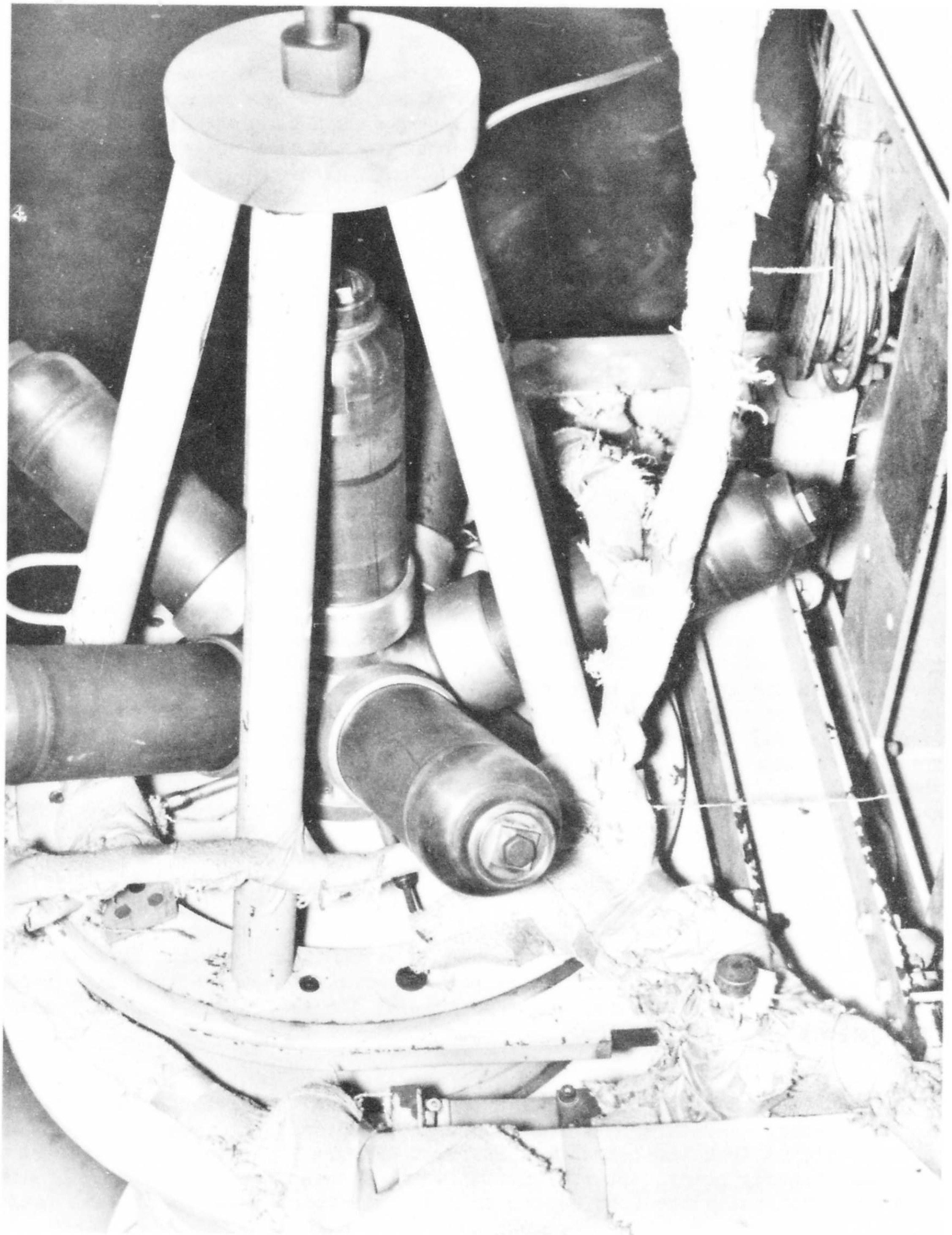


Figure 22. Forward View, HW-3, Run 004, Prefire

remained closed until T + 12 seconds when it was manually commanded to open, hot gas back flow from the diffuser over the motor caused complete loss of nozzle feedback, and at some point prior to web burnout, the chamber burned through at the aft end as a result of exposure to this feedback g·s.

7. Data Analysis HW-3 Run 004

(c) Review of the data from HW-3 Run `04 indicated that ignition was smooth with the maximum pressure attained being 500 psia at approximately 0.250 seconds, igniter burnout time. Shortly after igniter burnout, the motor chamber pressure dropped to a low of 355 psia due to the large initial throat area setting for ignition. The low pressure held until force control mode was cut in by the timer at T + 0.500 seconds, at which point the chamber pressure began to recover to the programmed 550 psia. For the first five seconds of the test the chamber pressure oscillated about the 550 psia predicted value at a frequency of about .75 cycles per second and an amplitude of about 25 psi, both slightly lower than those experienced during the first run. The average thrust level for the first five seconds of the test was 7600 pounds and the average chamber pressure for this same period was 510 psia, indicating that the propellant surface area burning was slightly higher on the average for this second test than it was for the first test. On command to extinguish, the motor chamber pressure dropped to a low of 32 psia and immediately recovered to an average pressure of 52 psia where it continued to burn for approximately five seconds. At the ten second point, the program called for the pintle to reinsert and the chamber pressure to recover to that of the motor at ignition prior to force mode control (about 350 psia). The chamber pressure only rose to 80 psia and immediately dropped back to 52 psia until about 11.2 seconds when it slowly began to climb. The peak pressure attained after this time occurred at 12.45 seconds and reached a value of 740 psia. Chamber pressure dropped immediately back to 52 psia and from this point until burnout of web, about 32-33 seconds, oscillated erratically about 100 psia with one spike reaching 230 psia.

(c) After the eight second point the data is for the most part worthless as the pintle feedback lines were burned through and any control forces input to the pintle were open-loop and entirely unrelated to those desired inputs. The point at which the chamber burnthrough occurred is not obvious from the data and was not evident from the films as the window clouded over at the five second point and remained that way for the remainder of the test. The chamber pressure and thrust as a function of time are shown on Figure 23.

(c) Input to the control system was 4100 pounds, the same as that to Run 003. For this test as for the first test, the program input records were not usable, therefore this function was calculated from program output and the error signal from the computer circuitry. Figure 24 shows the calculated input signal and clearly points out the time at which feedback was lost from the pintle potentiometer, namely the 7.60 second point. This point is a usable data point

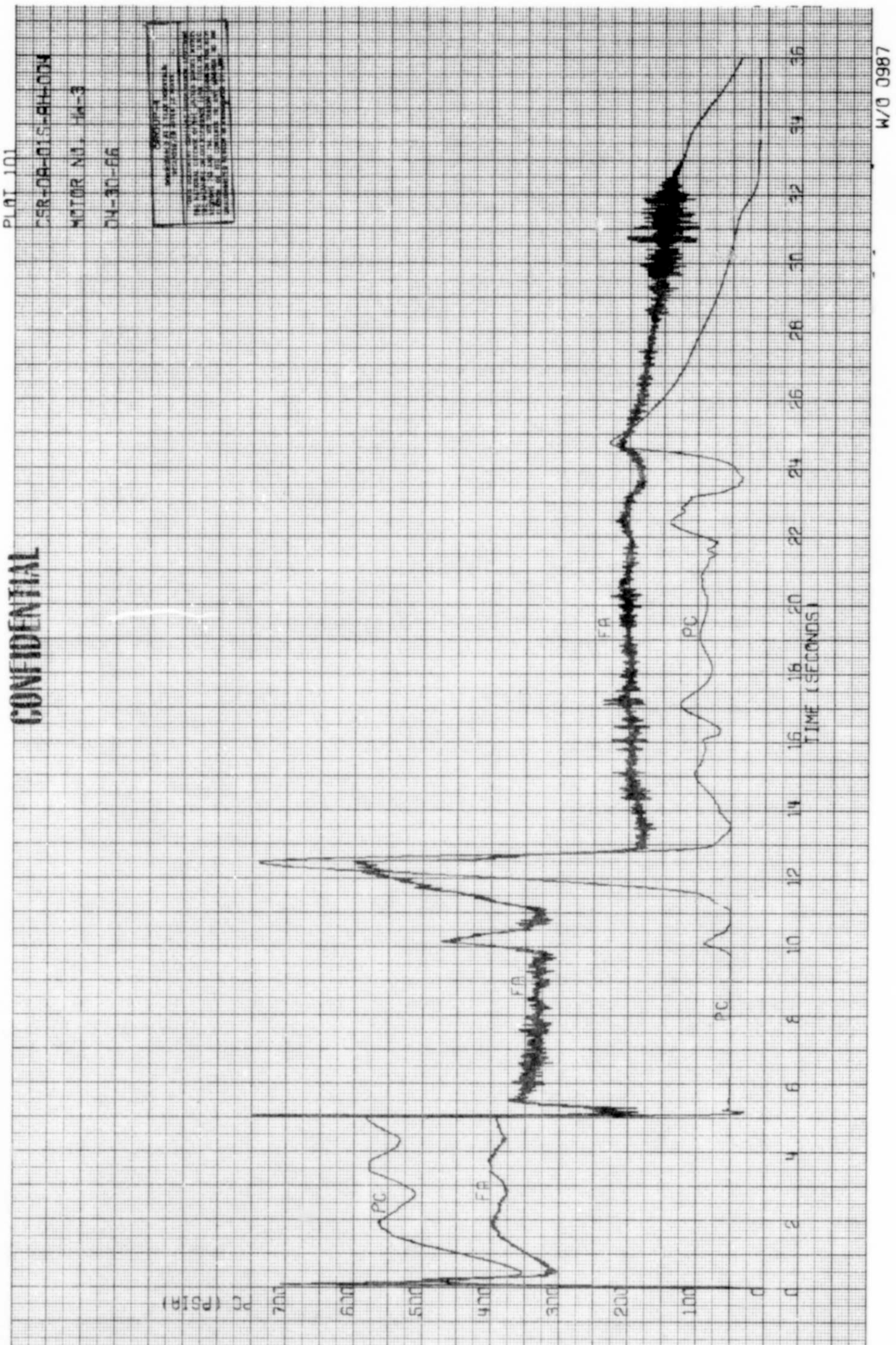


Figure 23. Thrust-Time and Pressure - Time, HW-3, Run 004, (u)

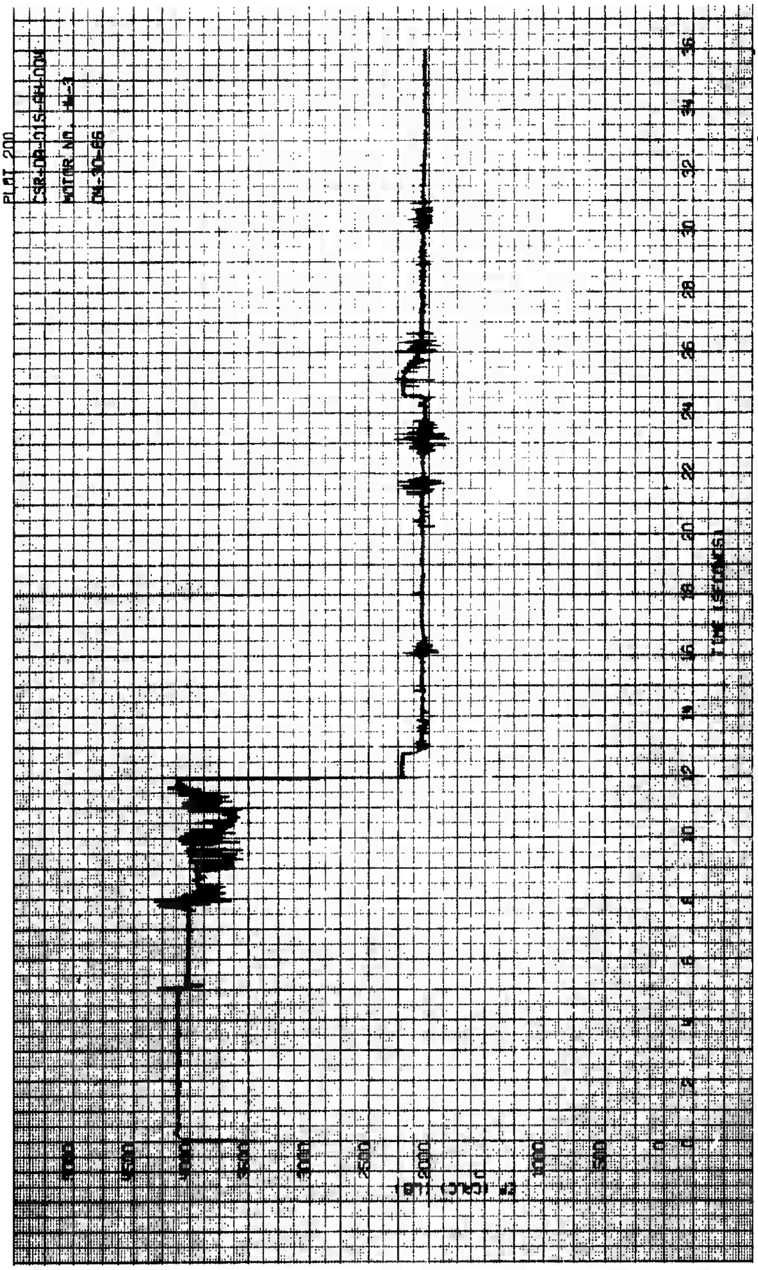


Figure 24. Program Input, HW-3, Run 004

although the programmer is being bypassed from the time of extinguishment command until the 10 second repositioning point. Even though it is not being used to control the motor from the 5 to the 10 second point, the computer is still calculating the feedback forces and attempting to compensate for them with signals to the servo valve. The servo valve is responding to the signals, however, the hydraulic supply to the servo valve is being shunted past the valve, through the fail-safe manifold, and returned to the hydraulic supply cart. Figure 25 shows the calculated feedback signal from the computer and indicates an incipient loss of feedback at the 7 second point with total loss at the 7.6 second point. All data on this figure beyond this time is worthless from an analysis standpoint.

(c) Figure 26 depicts the measured thrust divided by the measured chamber pressure as a function of time. The high frequency oscillations in this plot point out the effect of the back flow of gas over the aft end of the motor and the ringing of the test stand from this excitation. This plot is useful in determining the aerodynamic throat area of the nozzle during the controlled portion of this test and, in addition, indicates that the chamber burnthrough most likely occurred at about the 24.5 second point where the plot indicates an oscillation of increasing amplitude beginning. Since there is no longer a blockage at the end of the diffuser, the only feasible explanation for this amplitude increase is gas leakage from the motor case at some point other than the nozzle.

(c) Although it is almost useless, the weight loss trace has been included to show the magnitude of the unsymmetrical loads that were felt by this motor after the 5 second point and due to the gas back flow. This plot is shown on Figure 27. Stabilization of this parameter almost occurs at the 33-34 second point indicating a weight loss of about 400 pounds for the second test firing. Although this value is close to that which represents the remaining propellant after the first test, it is probably not accurate due to heat damage to the load cells and due to stand ringing.

(c) The absolute tank pressure is shown on Figure 28 as a function of time. This plot clearly shows the effect of gas blow back on the environment of the altitude facility. From the 5 second point until the 12.5 second point the pressure in the tank is continuing to increase. At the 12.5 second point, apparently, the trap-door was commanded to open allowing some semblance of order for the remainder of web burning. This figure also verifies the 24.5 second point as the most probable point of chamber burnthrough.

(c) Figures 29, 30, and 31 show the heat flux and chamber outside wall temperatures as a function of time. The severity of the environment can be seen from the rate of heat flux increase from the 5 second point on until loss of feedback from the heat flux meters. The most severe heating of the chamber occurred on the 180 and 270-degree side of the chamber. That is the side between the motor and the sidewall of the tank, away from the outlet to the nitrogen ejector. Loss of hydraulic pressure from the hydraulic circuit located on that same side of the motor verified the severity of the environment.

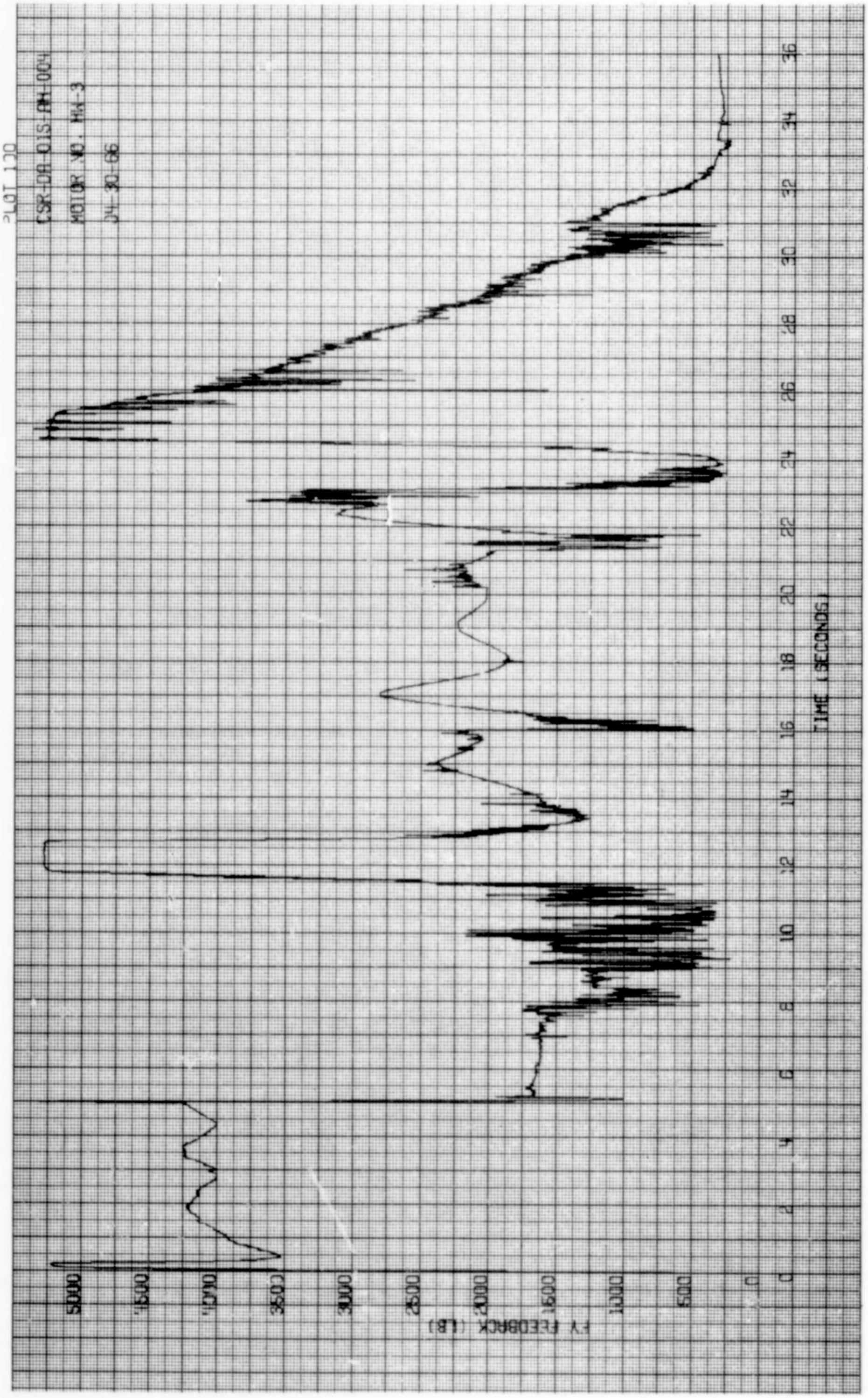


Figure 25. Feedback - Time, HW-3, Run 004

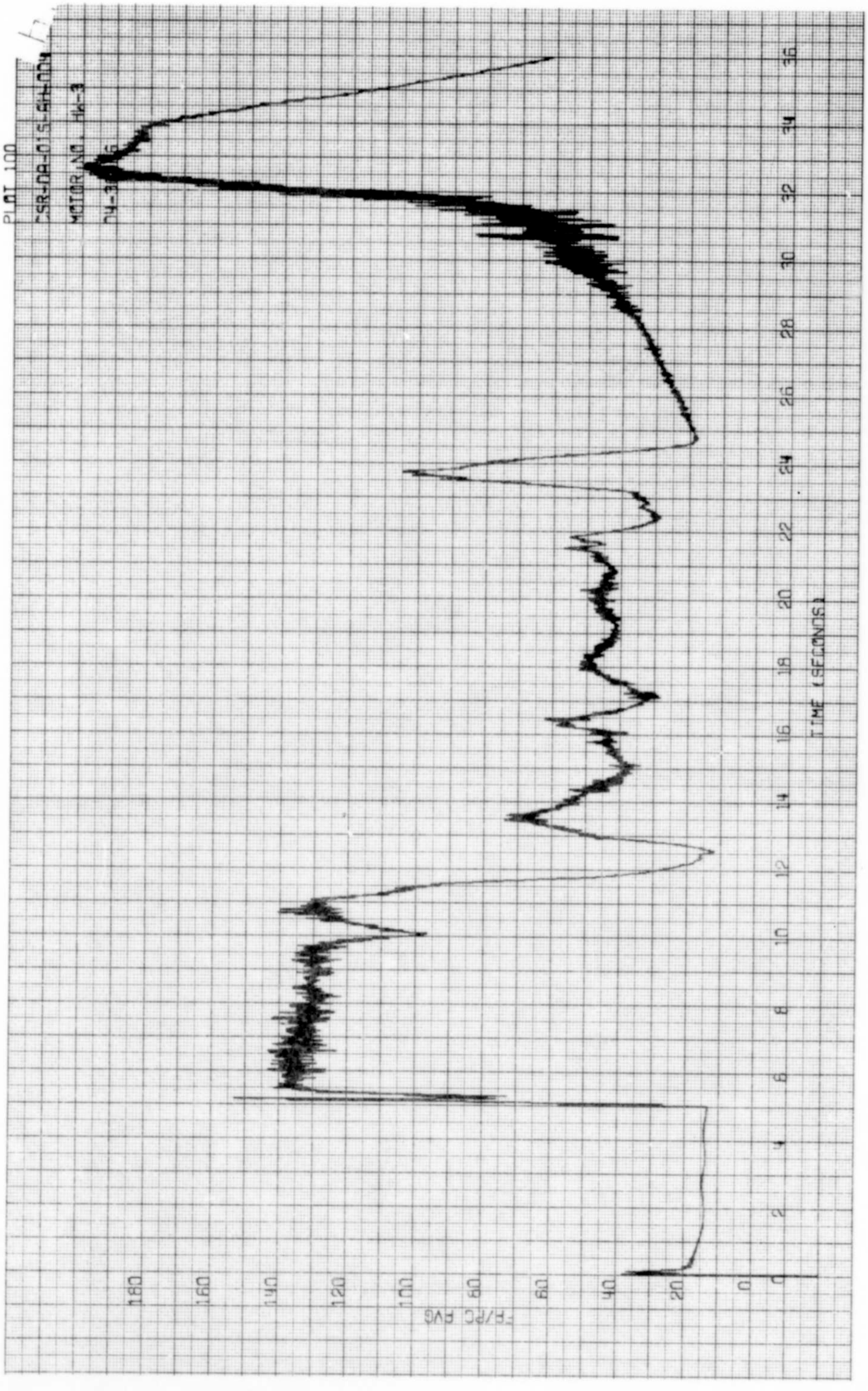


Figure 26. Thrust/Pressure - Time, HW-3, Run 004

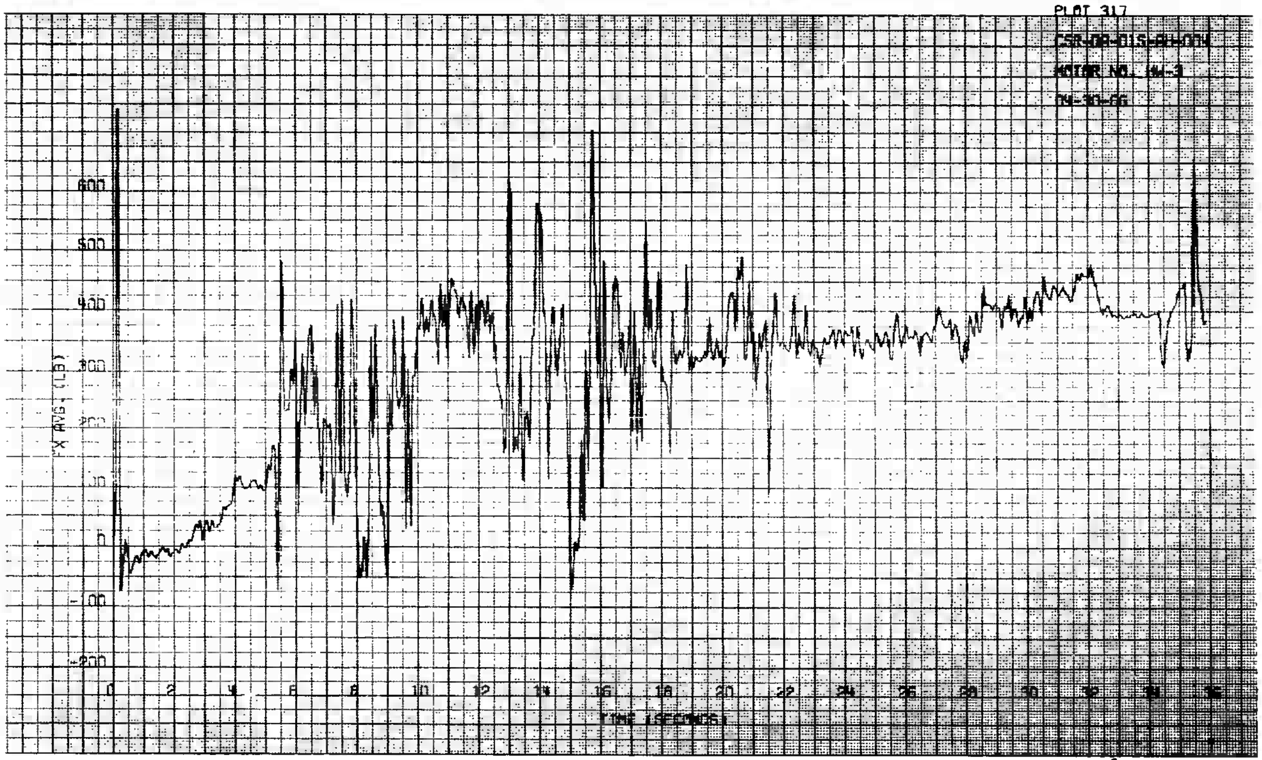


Figure 27. Weight Loss - Time, HW-3, Run 004

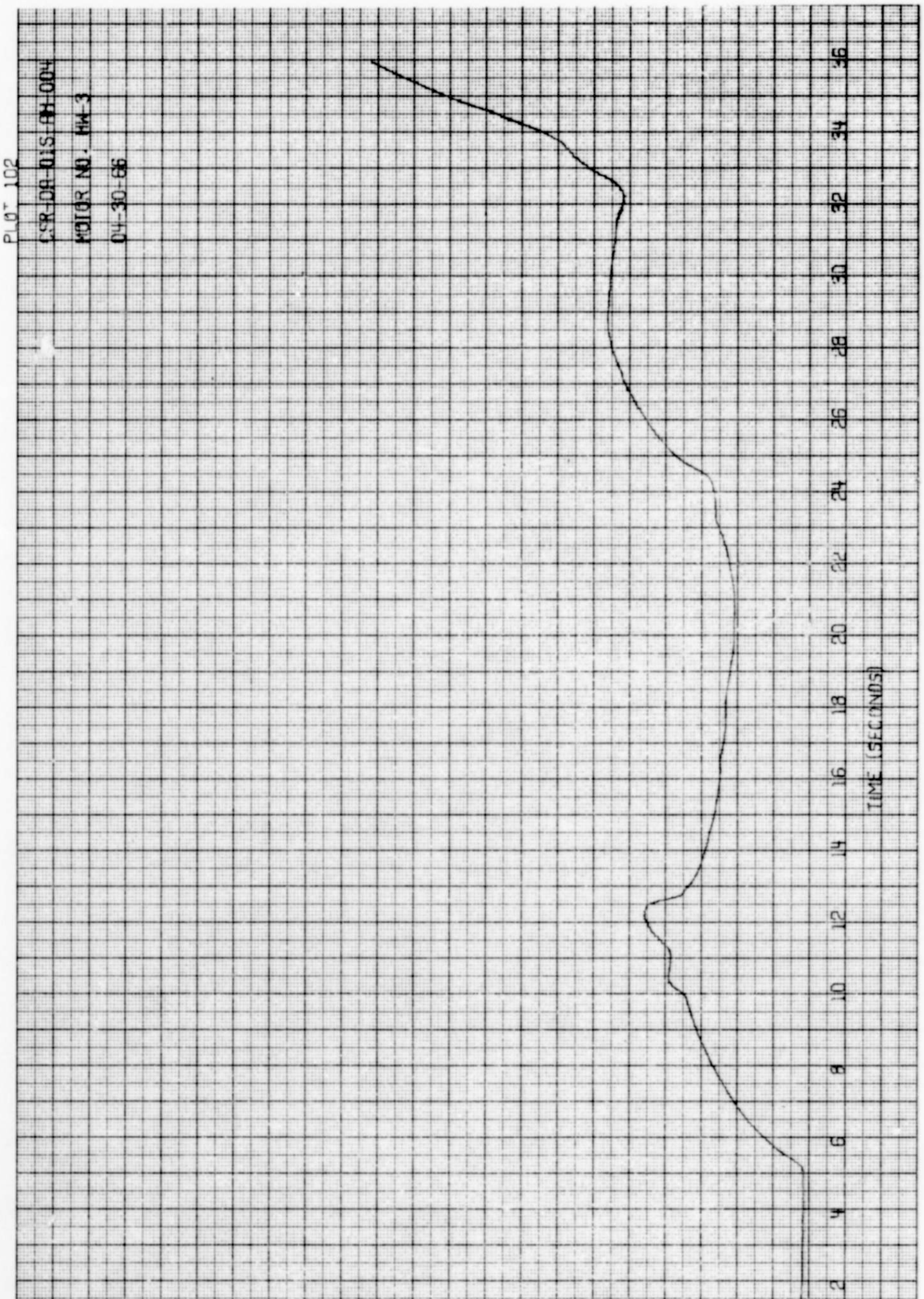


Figure 28. Altitude Tank Pressure - Time, HW-3, Run 004

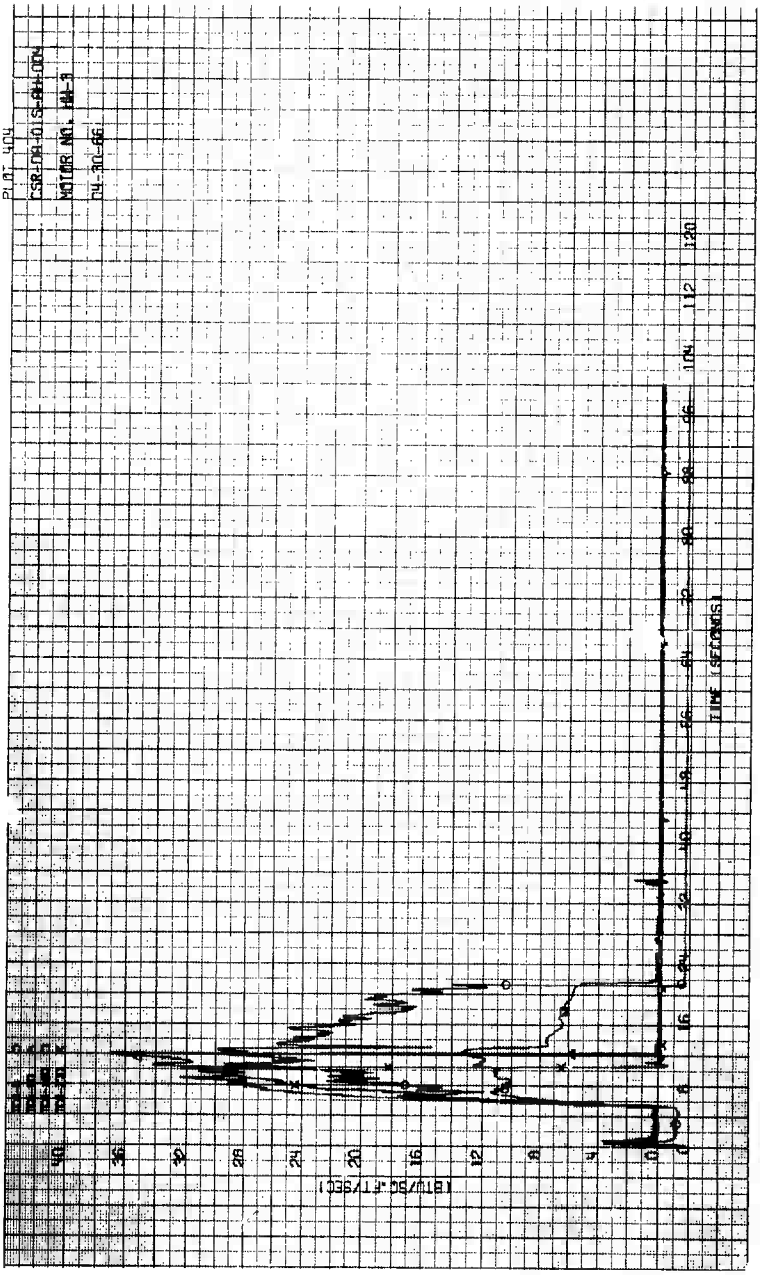


Figure 29. Heat Feedback - Time, HW-3, Run 004

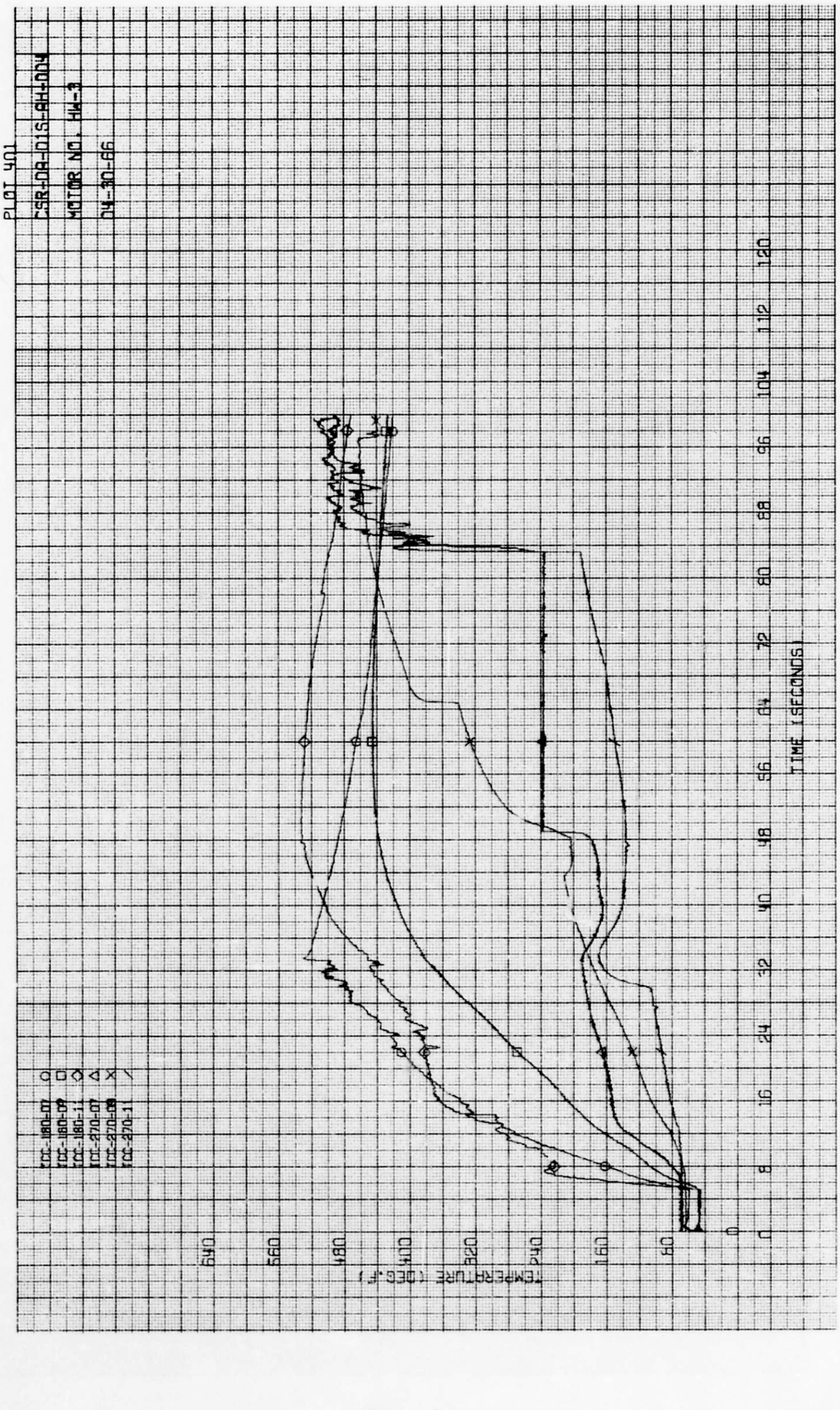


Figure 30. Chamber Thermocouples, HW-3, Run 004

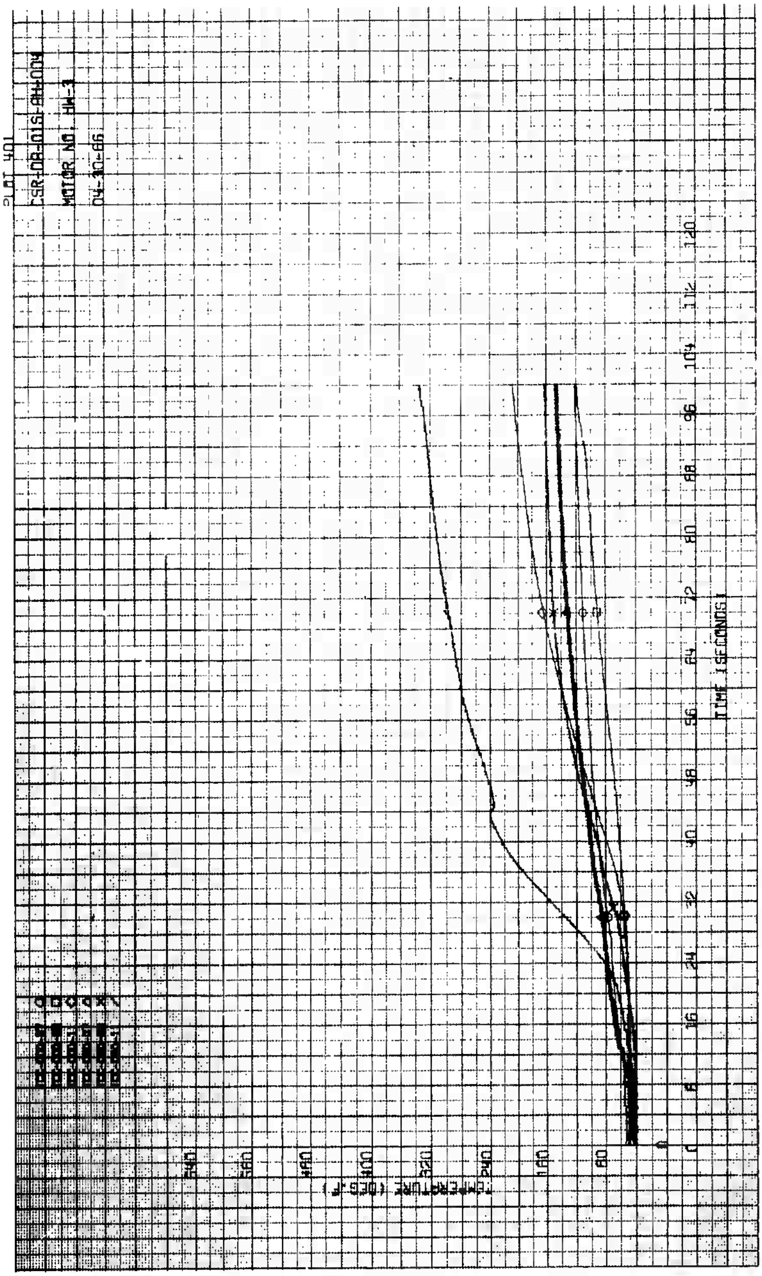


Figure 31. Chamber Thermocouples, HW-3, Run 004

III, A, Heavyweight Motor HW-3 (cont.)

(c) In summary, the analysis of the test data from HW-3 Run 004 indicated that the motor yielded the following performance data up to the loss of pintle position (7.6 seconds):

Duration:	Not Applicable (about 33 seconds)
Thrust: (5 second Control Period)	7600 pounds average 6000 pounds minimum 8000 pounds maximum 14,200 pounds ignition spike 15,000 pounds extinction spike
Pressure: (5 second Control Period)	510 psia average 355 psia minimum 580 psia maximum
Weight Loss:	Estimated at 140 pounds for the first 5 seconds
Is Delivered:	Estimated at 272 Lb-sec/lbm
Is Corrected: (Std. Conditions)	Estimated at 239+ Lb-sec/lbm
Impulse: (5.011 seconds)	38,183 pound-seconds
Pressure-Time: (5.011 seconds)	2585 psia-seconds
Nozzle Throat Area: (5 second Control Period)	8.45 square-inches average 7.85 square-inches minimum 9.20 square-inches maximum

These values presented above do not include any data after the first 5 - 5.5 seconds of firing. The minimum pressure attained was 32 psia approximately and occurred after the pintle had been retracted in a P-dot extinguishment mode. Stabilization occurred at 52 psia the same as it did on the aborted extinguishment of motor HW-2 fired at sea level. This indicated that the motor was reproducible in surface area, nozzle throat area, and burning rate with the pintle wide open. Cold flow testing of the nozzle after firing indicated that this wide open throat area was about 25.7 square inches rather than the expected 29 square inches and that the throat area was located between the outer throat insert and the aft insulator on the strutted housing. By removing this insulator and re-flowing the nozzle, it was determined that the actual sonic point moved back into the nozzle geometric throat plane and increased to a value of 28.5 square inches.

8. Postfire Hardware Evaluation HW-3 Run 004

(c) With the exception of the hole burned in the aft end of the chamber, the hardware was in remarkably good condition considering the severity of the external heating. An overall motor view is shown on Figure 32 and a closeup showing the hole in the chamber on Figure 33. The hole in the chamber is on the side opposite the ejector butterfly valve in the altitude facility and was probably caused by the recirculatory gas flow feeding back from the blocked diffuser and forced to flow around the motor to the ejector inlet. As can be seen from Figures 32 and 33, almost all of the silicon rubber insulation has been burned off or is charred through affording the motor little protection from the thermal environment. This material is a good external insulation when the thermal environment is primarily from radiant heat sources, however, it is limited in its ability to withstand direct impingement and high velocity flow.

(c) The aft end of the motor and a nozzle closeup view looking down the nozzle exit cone are shown on Figures 34 and 35, respectively. On Figure 34, the hydraulic control panel can be seen on the lefthand side of the motor. This panel sustained some heat damage, but for the most part, was generally in better condition than normally would have been expected. This was due, most likely, to the convective cooling that it received from the 20-odd gallons of oil that leaked through it during the test and after the hydraulic line between the strut and the panel was burned through. This oil, while it probably protected the control panel, ignited at the motor and became an additional heat source leading to the eventual burnthrough of the case. As can be seen from the nozzle closeup shown on Figure 35, the nozzle pintle and outer throat assembly were intact. There were some deposits of aluminum oxide and other condensed solids on the "A" section of the exit cone and on the exit cone extension, however the throat inserts were clean and appeared to be in excellent condition.

(c) Two views of the nozzle assembly as removed from the motor and with the exit cone extension removed are shown on Figures 36 and 37. This nozzle has the same general appearance as those that were tested on HW-1 and HW-2 with the exception of the entrance cap. On this motor the entrance cap was insulated with molded GenGard V-44, an asbestos and silica filled nitrile rubber compound normally used as chamber sidewall insulation. The forward end of the motor with the igniters still installed is shown on Figure 38. From the appearance of the igniter cannisters and the thrust tripod, it is evident that the environment at the forward end of the motor was only slightly less severe than that at the aft end.

(c) After the test, the nozzle was moved to the nozzle assembly area and careful disassembly of the components was undertaken. The exit cone extension, shown on Figure 39, was in excellent condition despite the rugged appearance of the component in the three photographs shown on Figure 39. The inside contour had suffered only deposition of condensed solids -- there was no erosion or ablation that could be measured and the parallel to centerline wrapped silica phenolic had not

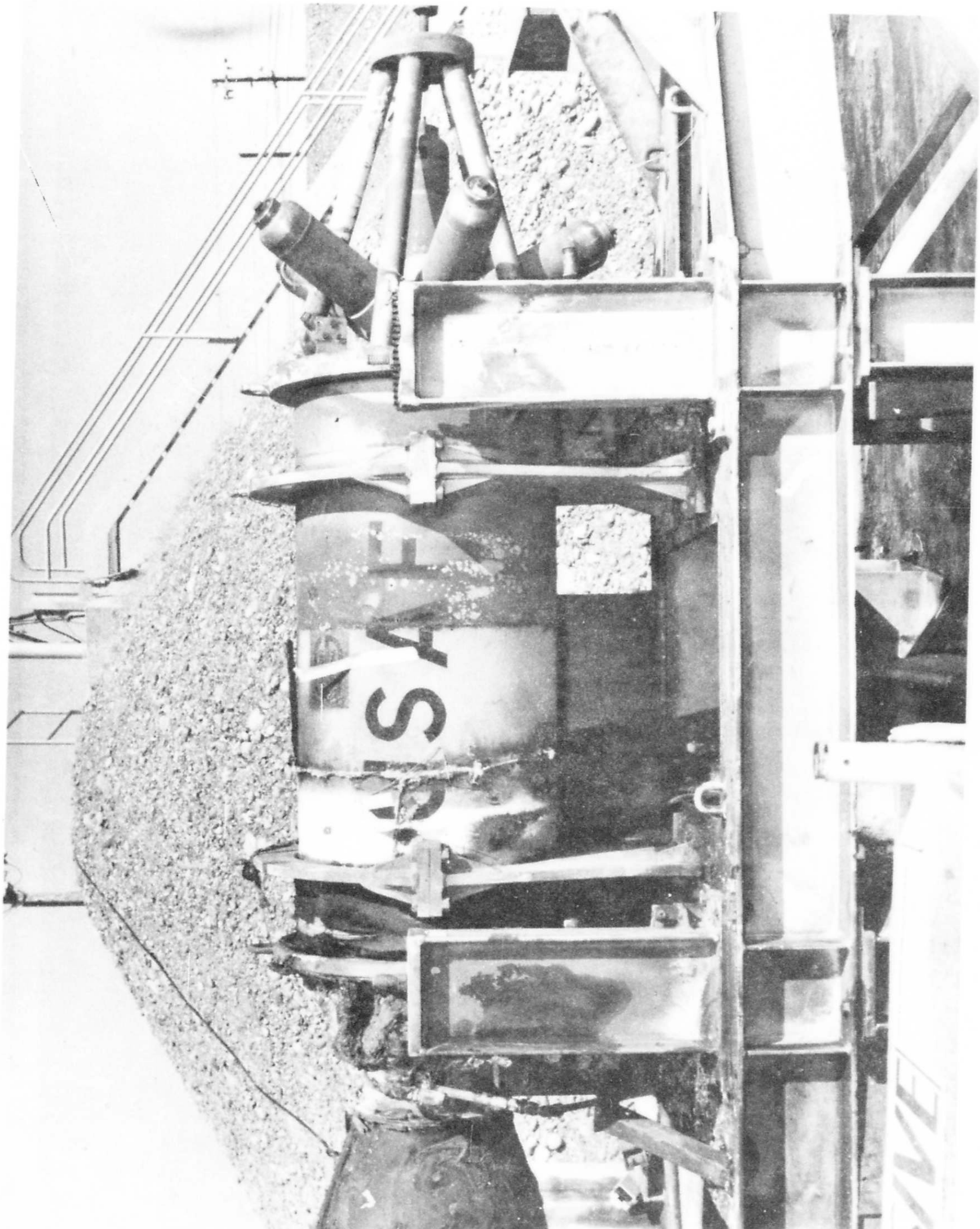


Figure 32. Overall View, HW-3, Run 004, Postfire

Figure 33. Rear - Side Closeup, HW-3, Run 004, Postfire

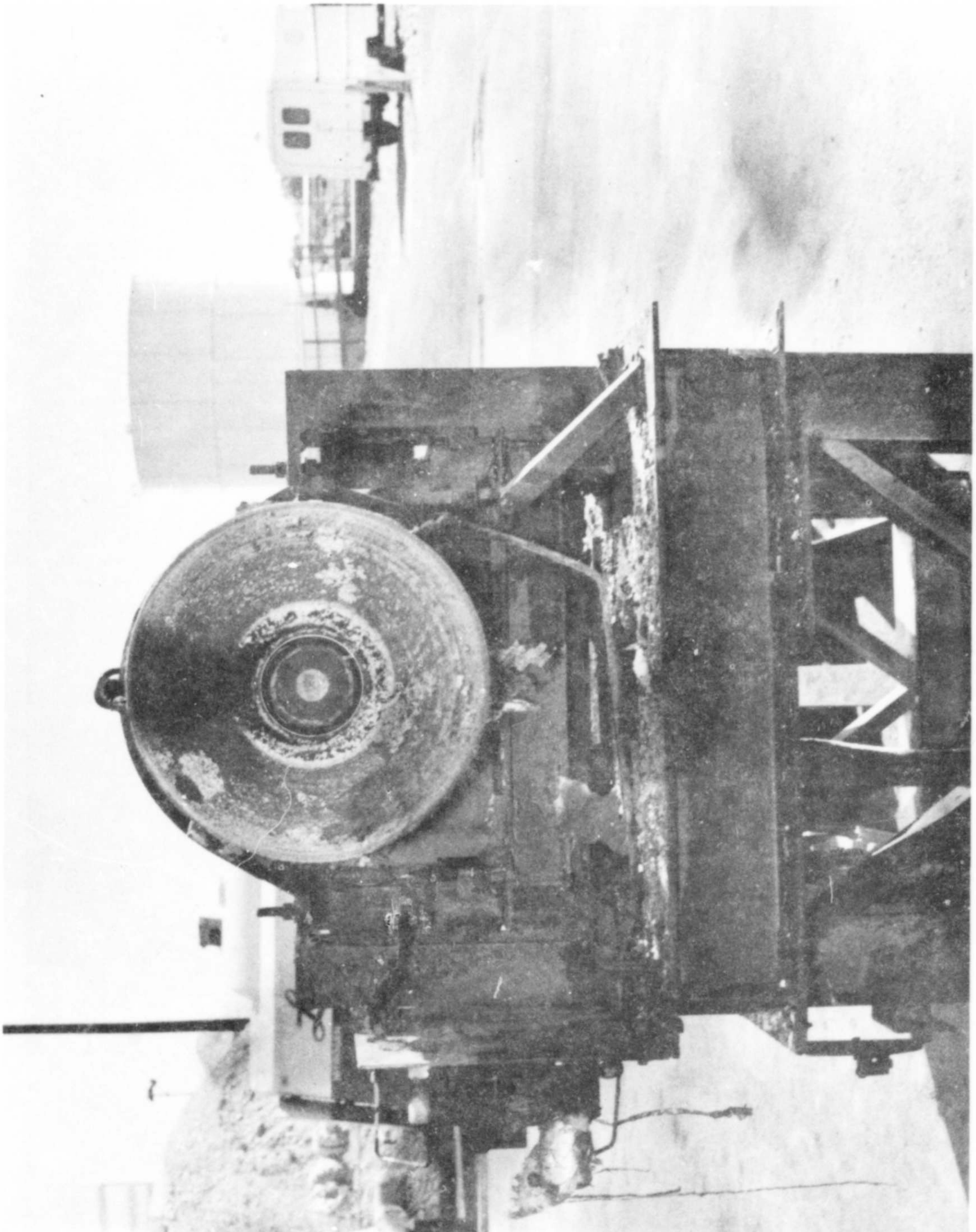


Figure 34. Aft View, HW-3, Run 004, Postfire

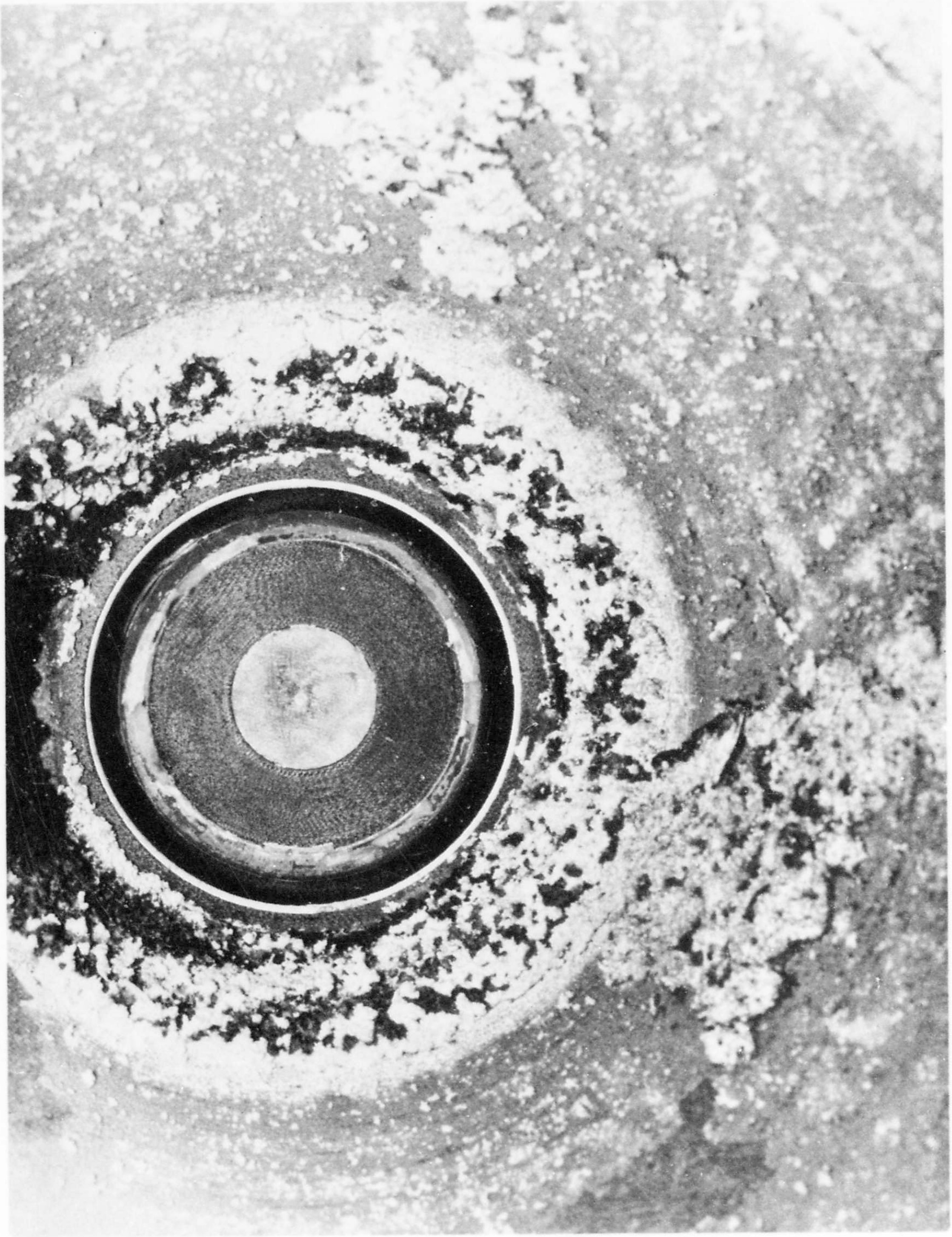


Figure 35. Nozzle Bore Closeup, HW-3, Run 004, Postfire

Figure 36. Nozzle, HW-3, Run 004, Postfire

Figure 37. Nozzle, HW-3, Run 004, Postfire

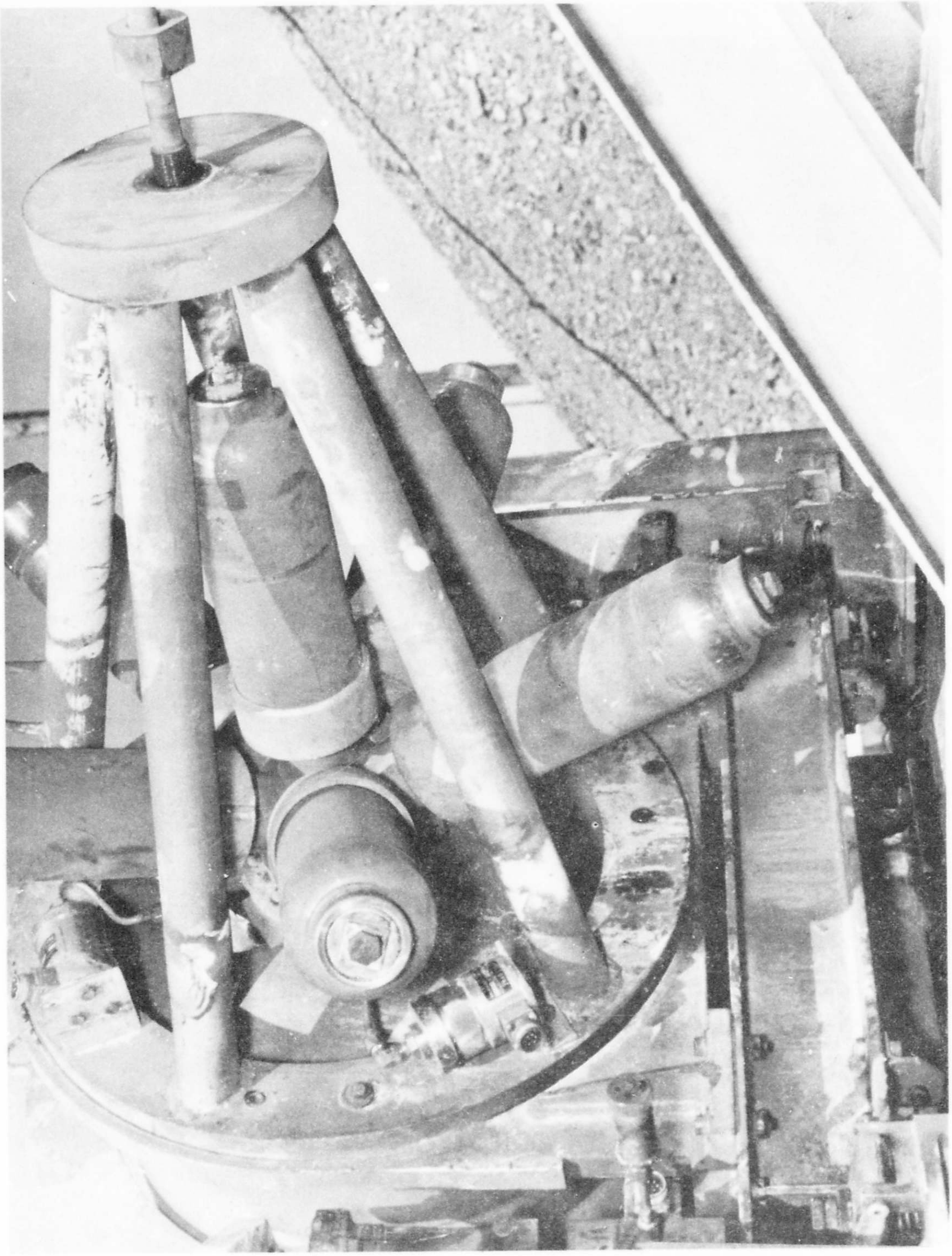
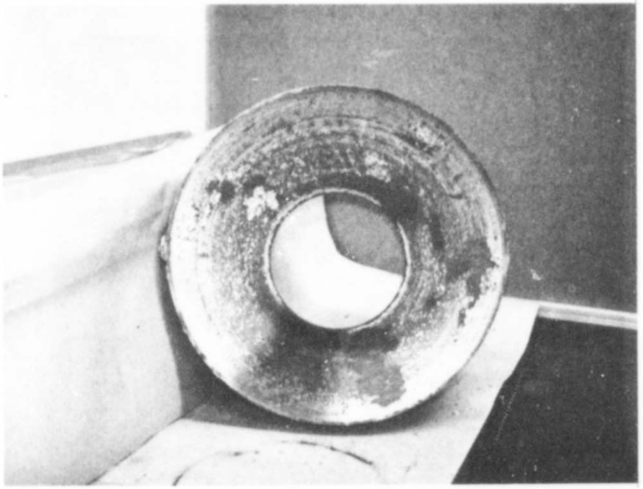
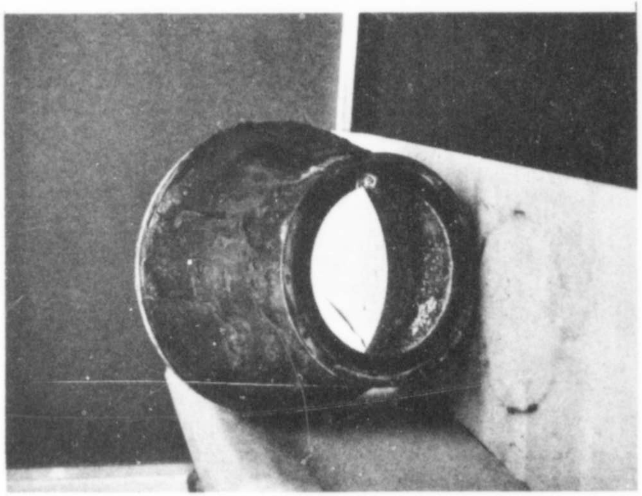


Figure 38. Igniters, HW-3, Run 004, Postfire



a. Exit Cone Extension - Postfire

b. Exit Cone Extension - Postfire



c. Exit Cone Extension - Postfire

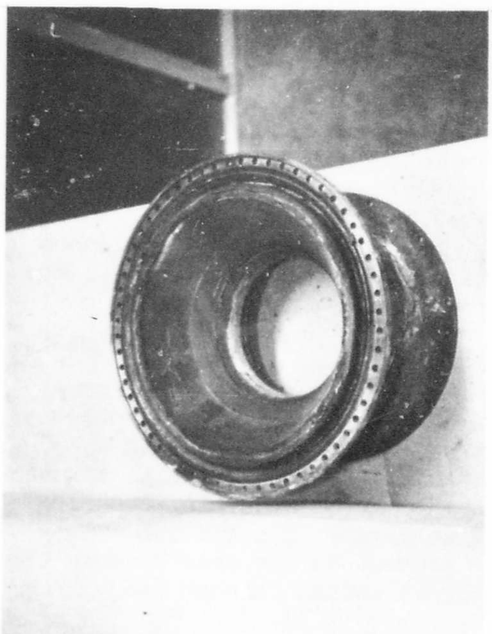
Figure 39. Exit Cone Extension, HW-3, Run 004, Postfire

delaminated. The seal between the exit cone extension and the outer shell had been subjected to considerable heat, however, the O-ring was still very pliable and would be expected to function as designed on a refire of the component. The glass-epoxy laminates that were overlaid to give added strength to the exit cone extension had pealed back and offered little to the structure. The steel flange, although blue over 75% of its surface, was still firmly attached to the liner and could be reused.

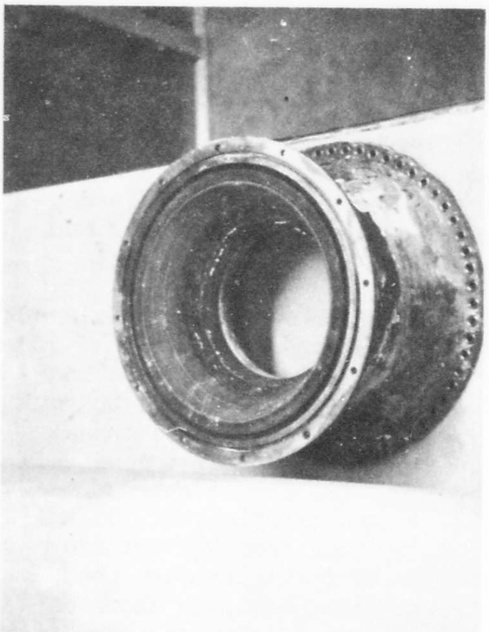
(c) Figures 40, 41, and 42 show the outer throat of the nozzle after firing in various stages of disassembly. This assembly and all of its components were in the same excellent condition that the components were in firings HW-1 and HW-2. Only the steel shell showed any signs of the severe thermal environment to which this motor had been subjected. The graphite phenolic throat support where it was exposed to the flame and the "A" section of the exit cone had ablated slightly, less than 1/8 inch at the maximum point. The throat approach, also a graphite phenolic component had less than 0.030 inches of ablation. On this test, the asbestos phenolic shell insulator had started to char from the outside diameter, receiving probably more heat through the outer shell than through the throat assembly or the throat approach. The crack in this component, as shown on Figure 41c, was a result of disassembly rather than any firing conditions. The pyrolytic graphite washer stack used as the outer throat insert and the graphite backup ring were not damaged during this test nor was there any sign of erosion or delamination of the individual washers.

(c) The strutted housing and pintle subassembly is shown on Figures 42, 43, and 44. The only visible points of damage to this assembly were to the strutted housing which was attached to the motor at the point of chamber burn-through and to the entrance cap rubber insulation which has previously been discussed. One of the hydraulic tubes had been burned off and a portion of the shear lip was missing. The actuator withstood the test firing in excellent condition, and in fact, appeared to have seen less heat than that fired on HW-1 -- a full duration sea level test. This is probably due to the better seal between the strutted housing and the strutted housing insulation on this part than on the first component molded. The inner bore of the strutted housing on this nozzle was in the best condition of any of the nozzles tested to date. This was a lucky coincidence as after 8 seconds into the second firing, pintle control was lost. Evidently, the pintle did not move back into the bore, but instead remained in the nozzle outer throat for the duration of this test.

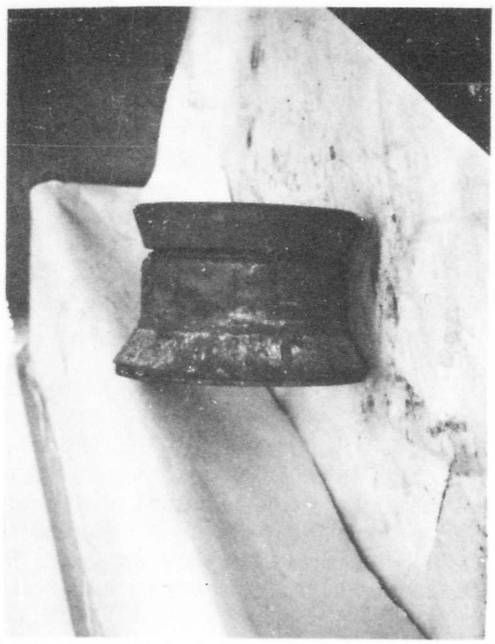
(c) The pintle subassembly and the actuator are shown on Figures 44, 45, 46, and 47 with the pintle in various stages of disassembly. The components of the pintle and actuator were intact and from outward appearances, were in excellent and refirable condition. There was one notable exception to this, however, and that being a very critical component of this assembly. The main pintle O-ring was badly charred through and cracked as can be seen on Figures 45a and 45b. This O-ring seals between chamber gas and the outside environment as the area between the actuator and manifold assembly and the pintle assembly is vented through the



a. Outer Throat - Postfire



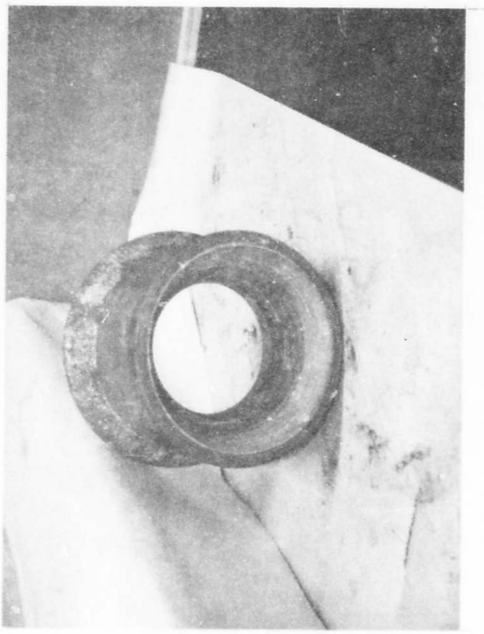
b. 'A' Section & Outer Throat - Postfire



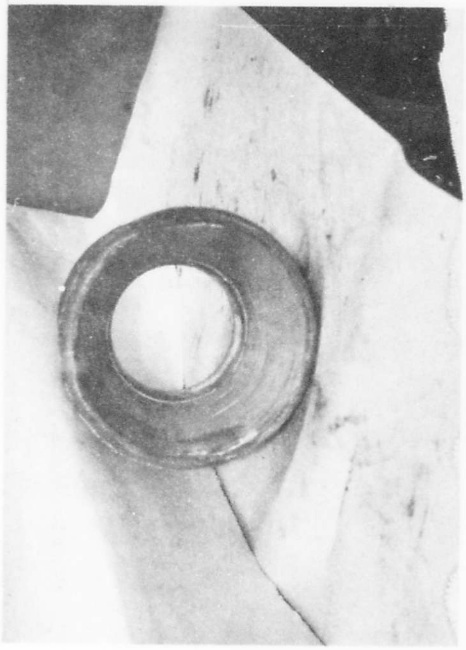
c. Outer Throat Inserts - Postfire

d. Outer Throat Inserts - Postfire

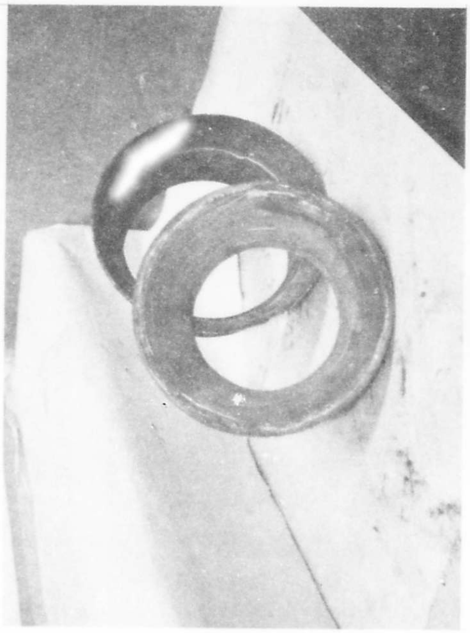
Figure 40. Outer Throat, HW-3, Run 004, Postfire (u)



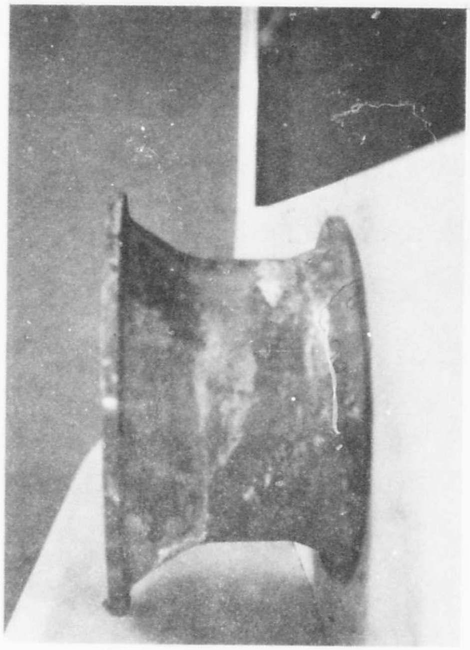
a. Outer Throat Inserts - Postfire



b. Outer Throat Inserts - Postfire

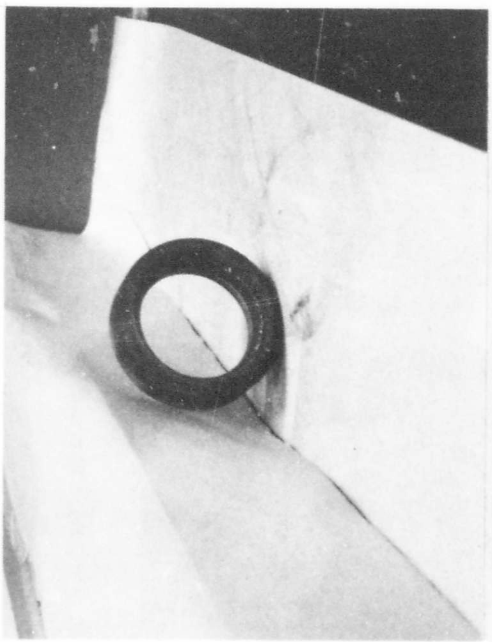


c. Throat Approach & Insulator - Postfire



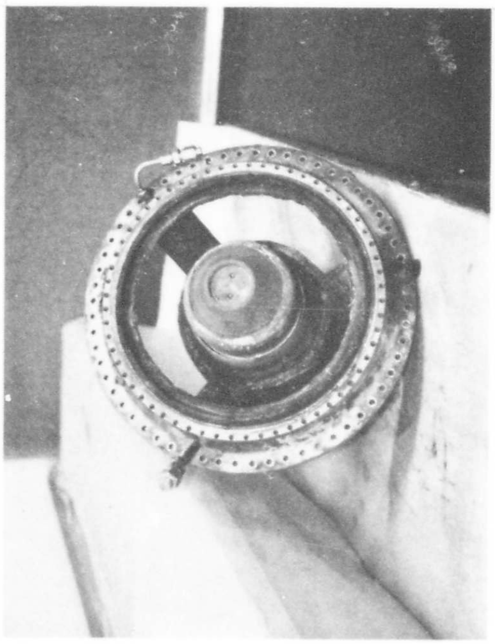
d. Shell - Postfire

Figure 41. Outer Throat Components, HW-3, Run 004, Postfire (u)



a. Throat Support - Postfire

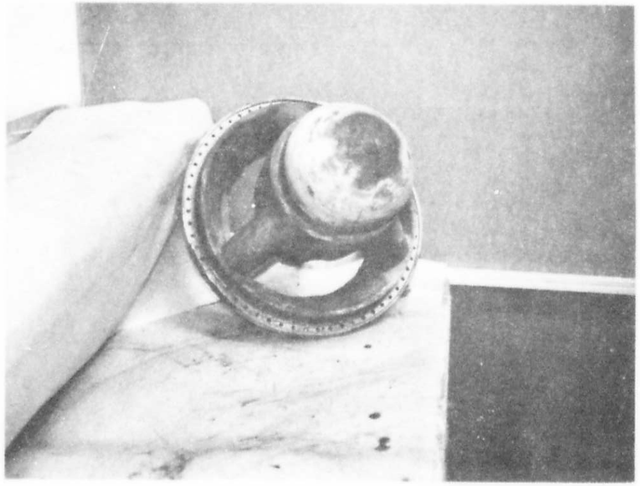
b. Pyrolytic Washers - Postfire



c. Pintle & Housing Subassembly - Postfire

d. Pintle & Housing Subassembly - Postfire

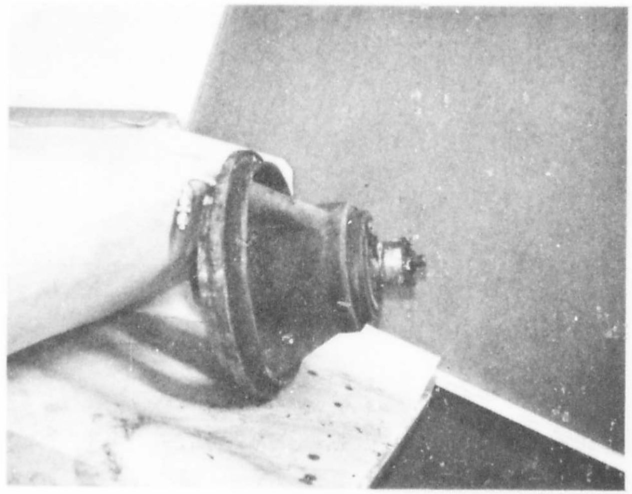
Figure 42. Outer Throat Insert and Strutted Housing, HW-3, Run 004, Postfire (u)



a. Pintle & Housing Subassembly - Postfire

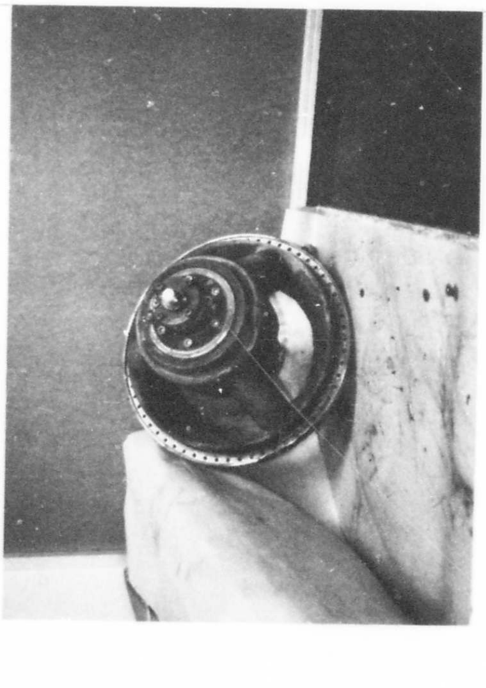
b. Pintle & Housing Subassembly - Postfire

c. Pintle & Housing Subassembly - Postfire

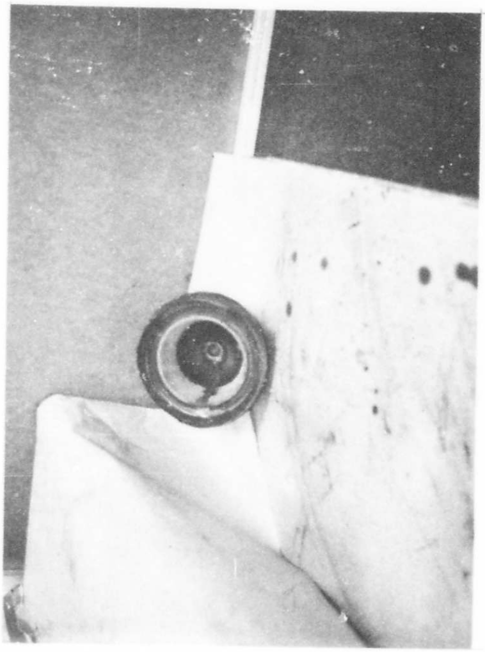


d. Pintle & Housing w/o Entrance Cap

Figure 43. Strutted Housing and Pintle, HW-3, Run 004, Postfire (u)

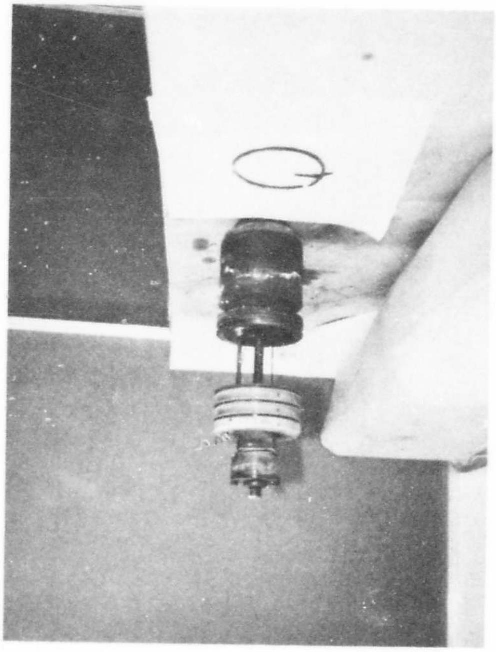


a. Pintle & Housing w/o Entrance Cap



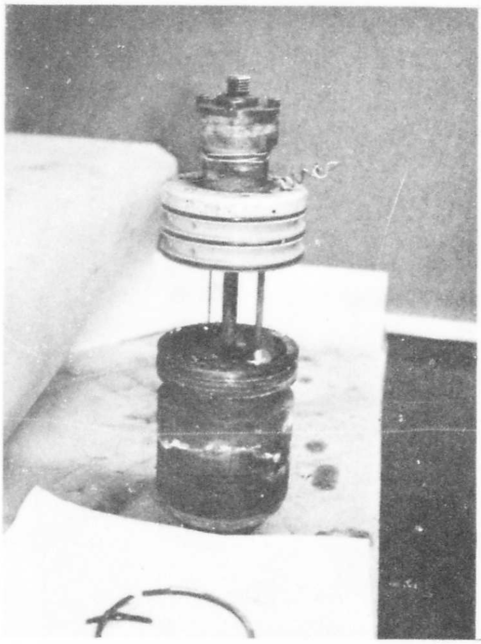
b. Entrance Cap - Postfire

c. Housing - Postfire

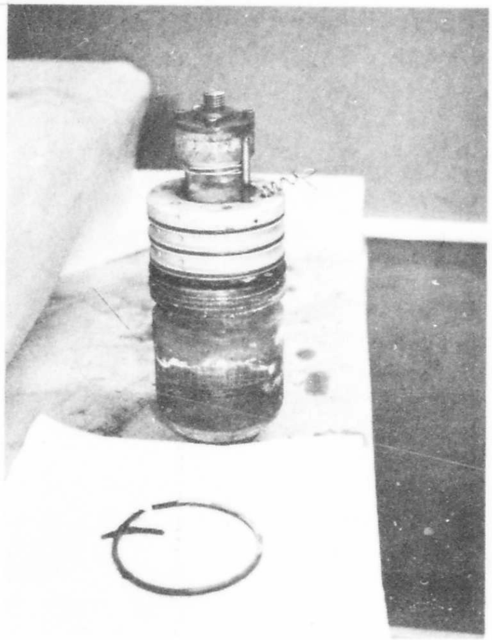


d. Pintle & Actuator Subassembly - Postfire

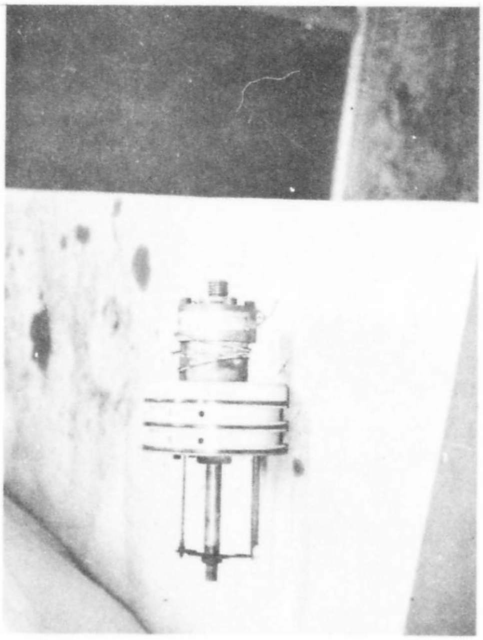
Figure 44. Strutted Housing and Pintle, HW-3, Run 004, Postfire (u)



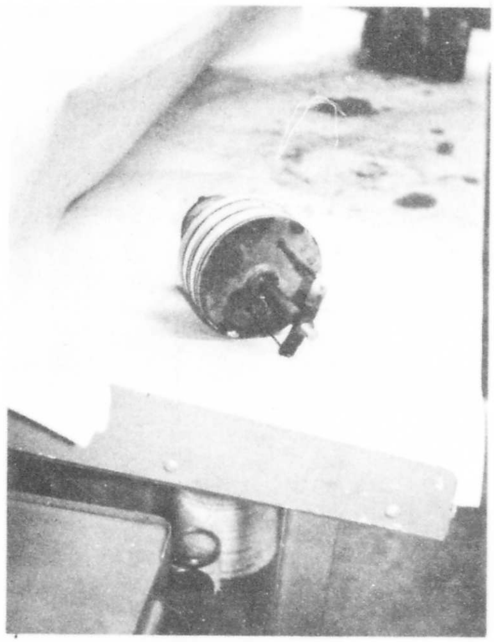
a. Pintle & Actuator - Postfire



b. Pintle & Actuator - Postfire

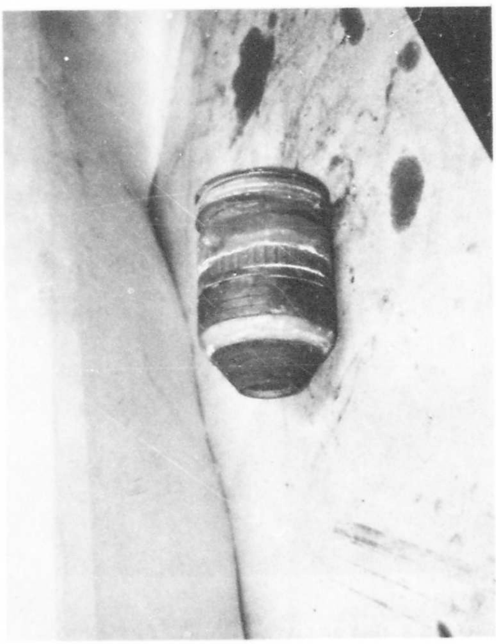


c. Actuator - Postfire



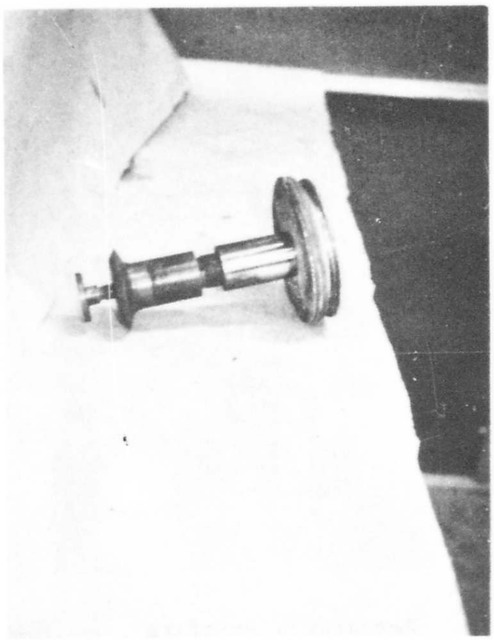
d. Actuator - Postfire

Figure 45. Pintle and Actuator, HW-3, Run 004, Postfire (u)



a. Pintle Subassembly - Postfire

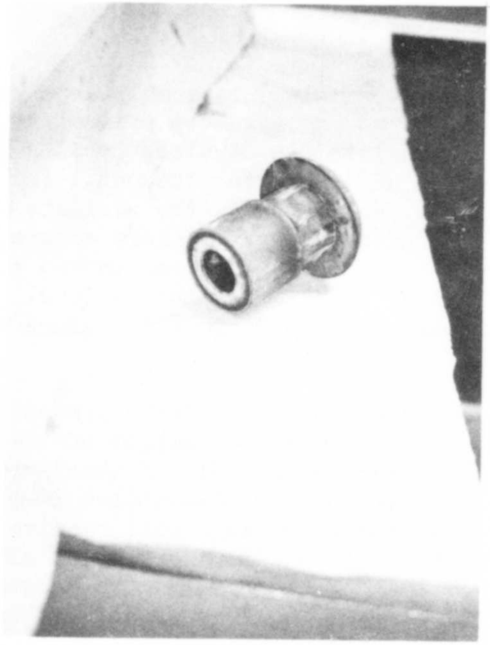
b. Pintle Subassembly - Postfire



c. Pintle Structure - Postfire

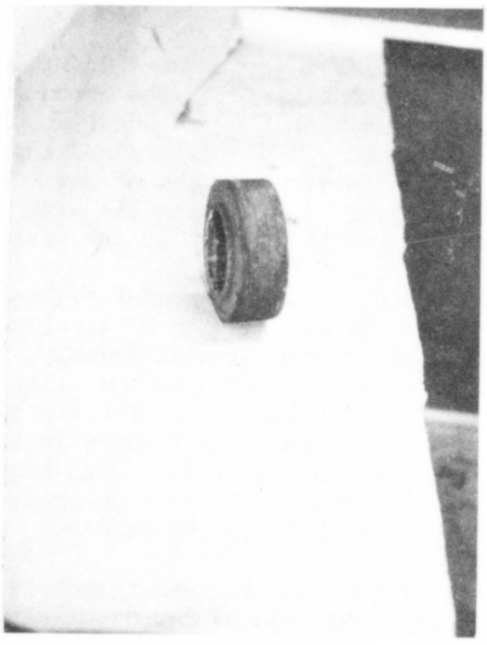
d. Pintle Structure - Postfire

Figure 46. Pintle Disassembly, HW-3, Run 004, Postfire (u)



a. Pintle Insulators - Postfire

b. Pintle Flame Liners - Postfire



c. Pintle Throat Insert - Postfire

d. Pintle Throat Insert - Postfire

Figure 47. Pintle Components, HW-3, Run 004, Postfire (u)

three struts. In fact, all of the O-rings in the pintle subassembly were badly charred and cracked although not one of them showed any evidence of leakage. It is possible that the excess heat that was pumped into the strutted housing by the burning oil after the test firing was the cause of the O-ring cookout. The temperatures that were experienced were probably somewhere in the vicinity of 800-1000 degrees, as the metal components did not indicate anything more severe. All of these O-rings are fabricated from Viton A, a material which has proven good at temperatures up to 1000 degrees for short periods of time without failure. Possibly, a silicone rubber compound should be substituted for the Viton A on future tests; this is being considered as a potential fix.

(c) The remainder of the components in the pintle assembly were in good condition and some of them will be reused on the lightweight nozzle test motors. The pyrolytic graphite washers will be reused from all of the three heavyweight motors as will the pintle support structure and the 90-tantalum 10-tungsten nuts. The incipient problems indicated by the charred O-rings will receive a very careful design review prior to the first lightweight test firing. As an alternate to the material substitution discussed in the previous paragraph, the volume between the pintle assembly and the actuator-manifold assembly will be sealed off in future tests. The maximum pressure differential that could be builtup between these components is limited to about 10 psi and that, less than ambient as the sealing will take place with the pintle withdrawn.

9. Conclusions of Test HW-3 Run 004

(c) The general conclusion drawn from firing HW-3 Run 004 is that the original failure was caused by inability to extinguish the motor without an automatic safety feature which would immediately open the trap-door at the end of the diffuser should the motor fail to extinguish. It was determined that all of the damage caused by this failure is attributable to the backflow of gas from the diffuser rather than any normal heat soak condition. In addition the after burning caused by the hydraulic leak probably contributed significantly to the damage.

(c) The above conclusion was drawn after a careful evaluation of the data as well as the components and comparison of the results of these analysis with the results of HW-1 and HW-2. To avoid a recurrance of this anomaly, it was necessary to determine exactly why the motor failed to extinguish the second time. There were three possibilities: (1) The rate of depressurization for any given pressure was much lower than that expected due to a mechanical failure in the components or a propellant grain crack; (2) The propellant requires a much higher than expected rate of depressurization in order to be successfully extinguished; (3) There was some external factor which caused extinguishment to be aborted.

(c) A very careful analysis of the oscillograph traces of HW-3 Runs 003 and 004 and those of HW-1 indicated that the rate of depressurization for any given pressure was not out of line with that which would normally be expected

at the given motor free volume and nozzle area change that transpired. Therefore, item (1) was ruled out as the probable cause of the failure to extinguish HW-3 Run 004.

(c) Rerunning of the rapid depressurization screening tests using insulated motors it was found that it takes a much higher rate of depressurization to extinguish the propellant than was originally anticipated. This rate, however should have been within the capability of the CSR motor at the free volume in question. In fact, the rate was within the CSR delivered rate for Run 004 down to a pressure of about 60 psia, at which point the rate of depressurization suddenly began to decrease rapidly, indicating that some external influence was present.

(c) Only one thing could externally influence the rate of depressurization of a venting motor; a change in the venting area. This change in the venting area could be caused by a motion of the pintle or by an unchoking of the motor at the nozzle and a rechoking at some other point. Since the pintle did not move, it became evident that the motor was being choked at some point other than in the nozzle. Calculations were made to determine what the possible choke points were and it was found that the area between the diffuser and the nozzle exit cone extension was the most likely point. This probability was verified by a review of the motor setup for the two tests, Run 003 and Run 004. Comparing Figure 5 with Figure 21, it can be clearly seen that the area between the nozzle and diffuser mouth has been reduced for the second test, Run 004. Whereas there was no silicon rubber compound between the nozzle exit cone extension for Run 003, this same area appears to have been almost closed for the second run. It has been calculated that this could have been the motor choke point at as high a chamber pressure as 60 - 70 psia, definitely causing a change in the rate of venting. If this became the "motor-throat", the "motor" would then consist of the standard CSR, the entire nozzle, and the entire 21-inch diameter by roughly 13 foot long diffuser. With the "motor" free volume encompassing all of these components, it is understandable that the rate of venting would be seriously reduced.

(c) Having established the most probable cause of the abortive extinguishment attempt on HW-3, the approach was taken to establish the most practical and quickest solution to the problem. It has been determined that the motor would most liekly have extinguished successfully had the silicon rubber compound not been used on the nozzle and blocked the diffuser entrance. However, during the propellant reevaluation P-dot screening tests in insulated motors, it became evident that an extinguishment problem would still exist as the motor free volume is increased due to propellant consumption. Conservative estimates place the number of successful extinguishments that could be expected in the present CSR design as that number that could be conducted within the first 60 - 70% of propellant web. The last 30 - 40% of web would probably not be extinguishable due to the large free volume and the correspondingly slower rate of venting with the present nozzle design. From this determination, it became necessary to consider making a change in the motor as well as simply eliminating the diffuser problem. This motor change could be one of three changes in design: (1) Change the propellant to a more extinguish-

able formulation; (2) Increase the nozzle outer throat diameter by about 2 inches and the pintle by about 2.1 inches in order to increase the maximum nozzle throat area without changing the minimum area; and (3) Short cast the next motors with AAB-3220 to lower the minimum attainable pressure.

(c) Of the three alternatives, the most attractive from a design standpoint is the change in nozzle diameter as this would allow a better packaging of the nozzle pintle and actuator, provide more flexibility for structural design, and allow the use of the present propellant which is fully compatible with the grain design and the nozzle materials that have been demonstrated. This approach is, unfortunately, the most impractical from a cost and schedule standpoint. Major changes in the nozzle would require that new motor cases be fabricated with larger aft boss, that all nozzle hardware would be redesigned and new hardware fabricated before any further testing, and that a new actuator design be formulated for the increased loads imposed upon a larger pintle. This approach was ruled out for the remainder of contract AF 04(611)-10820 due to the financial aspects. This current contract was budgeted based upon reuse of the chamber and nozzle structural hardware. All processing tooling would also require rework if the chamber boss size was altered, causing cost and schedule problems. Therefore, only the other two alternatives could be used.

(c) Based upon a time and schedule analysis, it was decided to attempt to find a propellant formulation with was more easily extinguished than AAB-3220, that had the same physical properties, and that had a more favorable burning rate. A time limitation was placed upon this effort with the decision date to be mid-July 1966. If at that time a suitable propellant substitution could not be found, the lightweight motor series would be short cast to lower the minimum chamber pressure attainable with the current hardware and improve the extinguishability of the CSR motor. This last choice would result in a limitation of the thrust variability as well as lower the mass fraction of the motor. This decision has yet to be made, however, some of the propellant work accomplished to date in this reevaluation effort is reported in section III-C of this report. To date, the possibility of finding an alternate propellant is very promising.

B. SPECIAL TEST EQUIPMENT

In the category of special test equipment, there were two items that received attention during the past quarter. These items were the diffuser assembly used to maintain altitude during the simulated altitude tests of the controllable solid rocket motor and the pressure feedback control system used to control thrust variability and extinguishment of the CSR. A third item, the casting cores for the CSR 'Finocil' grain configuration were modified slightly to accomodate the new grain configuration. This core modification consisted of the removal of approximately 60% of the fin surface area from the six symmetrical fins located in the forward portion of the motor. This surface area removal was necessitated to compensate for the increase in surface area at the aft end of the grain since the restriction material used in the heavyweight motor development effort will be removed for the motors in the lightweight motor development effort. As this change is a minor one, no further discussion is warranted.

1. Diffuser Modification

The original design of the diffuser used the straight tube type of diffuser 21 inches in diameter and about 13 feet long. This required that the nozzle exit cone extension be located such that the clearance between the nozzle and the diffuser sidewalls was held at a constant value of slightly less than one inch. To accomplish this, the nozzle was located so that it protruded into the diffuser approximately 4 inches. As was discussed in the conclusions to CSR test HW-3, Run 004, this close tolerance clearance requirement was probably the cause of the anomaly in Run 004.

The initial area for which the diffuser was designed was approximately 40 square inches, using a flat plate type of entry. To increase this area, thereby minimizing the possibility that a similar anomaly will re-occur, it is necessary to contour the entry of the diffuser to smooth the flow at the entrance. This work is currently being accomplished by adding a contoured ring to the diffuser entry. The addition of the ring will allow the nozzle exit cone extension to be backed off so that it is out of the diffuser completely. By locating the nozzle, a fixed distance away from the diffuser mouth, it is possible to increase the area from the approximate 40 square inches to approximately 100 square inches without affecting the performance of the diffuser. This new entry area is a conic surface, at about a 30-degree angle to the diffuser centerline. The area is formed between the aft-outer edge of the nozzle and the 2-inch radius of curvature of the bell-mouthed diffuser entry. By using this type of test setup, the entry area is basically independent of the amount of insulation used on the nozzle exit cone extension.

In addition to the change to the diffuser entry, a series of four pressure pickups are being installed in the diffuser. The first of these pickups is located approximately 4 feet downstream of the diffuser entry with the other three located at an axial spacing of 31 inches. These pickups will provide a pressure profile on future tests and will provide data necessary to evaluate the

III, B, Special Test Equipment (cont.)

diffuser performance as well as determine the backpressure to which the nozzle exit plane is subjected.

2. Pressure Feedback Control System

For the first three test firings of the controllable solid rocket motor, a "breadboard" control system was employed to vary the thrust and extinguish the motors. This breadboard system employed the PC-12 computer circuitry that was to become the final control system, however this circuitry was temporarily patched into the stationary equipment in control room W-3 at Aerojet's Sacramento Solid Rocket Test Facility. All of the timing and amplifying functions required by the control system, other than those inherent in the computer, were externally supplied using available control room facilities. As this setup was not compatible with the program requirements of firing two motors at the Arnold Engineering Development Center, an integrated, portable console was designed and fabricated to provide all of the control functions necessary to fire, vary thrust, and extinguish the single-chamber controllable solid rocket motor. This integrated system requires inputs in the form of 28 VDC - 10 Amp, 115 VAC - Single Phase - 60 cycle - 10 amps, and the normal motor feedback signals of chamber pressure, pintle position, and thrust to completely control the CSR motor. As the two power supply requirements are available in almost any motor test facility, including portable test units, the CSR motor can be test fired at any facility without special setup and at nominal cost. A brief description of the console and its operation is provided in the following paragraphs.

The pressure feedback control system, as packaged in a Stantron F1500-25 console cabinet, is shown on Figure 48. The console incorporates illuminated push button switches, indicators, meters monitoring pintle position, chamber pressure and thrust. A hand operated "throttle" is provided to give the test conductor manual control over the controllable solid rocket motor. The system is also provided with the flexibility of remote programmer input if it is found more desirable to test the CSR with a preselected program rather than manually. The console houses a 3-shelf PC-12 analog computer, sequence control circuits, pressure transducer conditioning circuitry, interface connector panel, igniter select and firing circuit.

The console consists of four sections: (1) the console lid, Figure 49, which incorporates the indicators and controls; (2) the sequence circuitry, Figures 50 and 51; (3) the computer section, Figures 52 and 53; and (4) the interface connection panel, Figure 54.

a. Console Lid - Figure 49

The console lid is divided into three sections: (1) indicator, (2) control, (3) igniter selector. The indicators provide visual display of the mode of the sequence circuitry at all times. Indication is given by the meters of plug position, chamber pressure and thrust. The light indicators functions are:

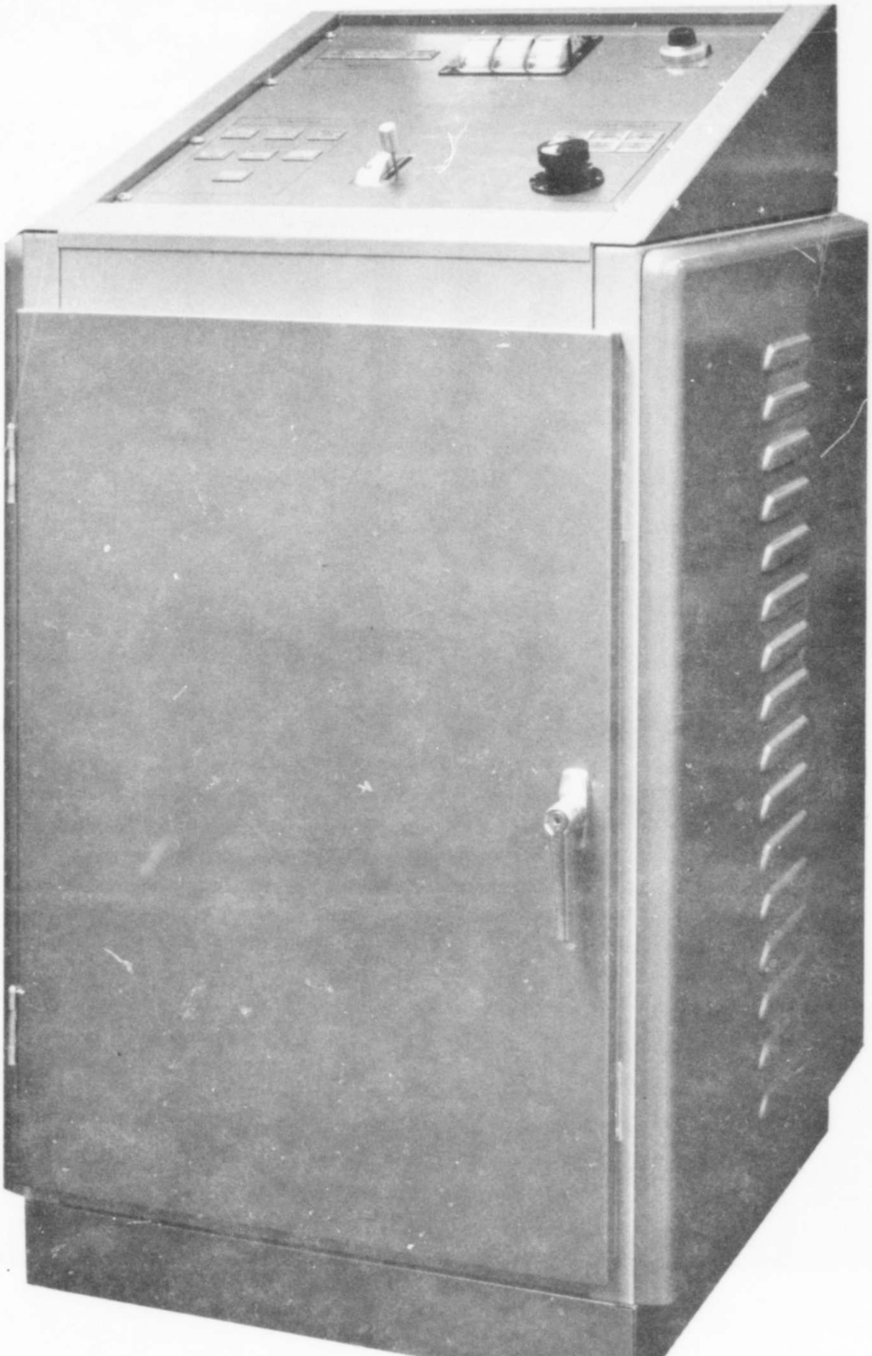


Figure 48. Pressure Feedback Control Console

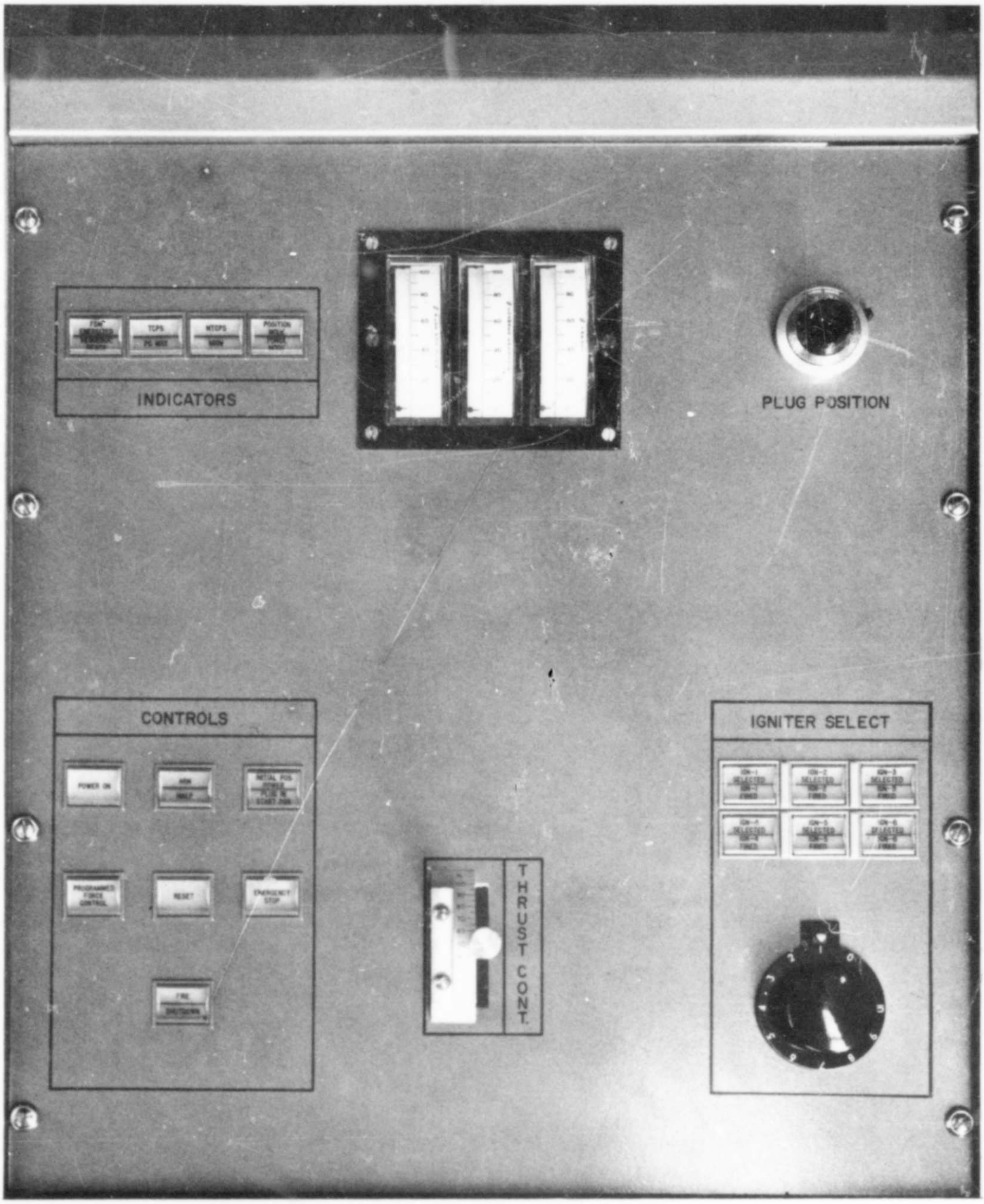


Figure 49. Console Lid

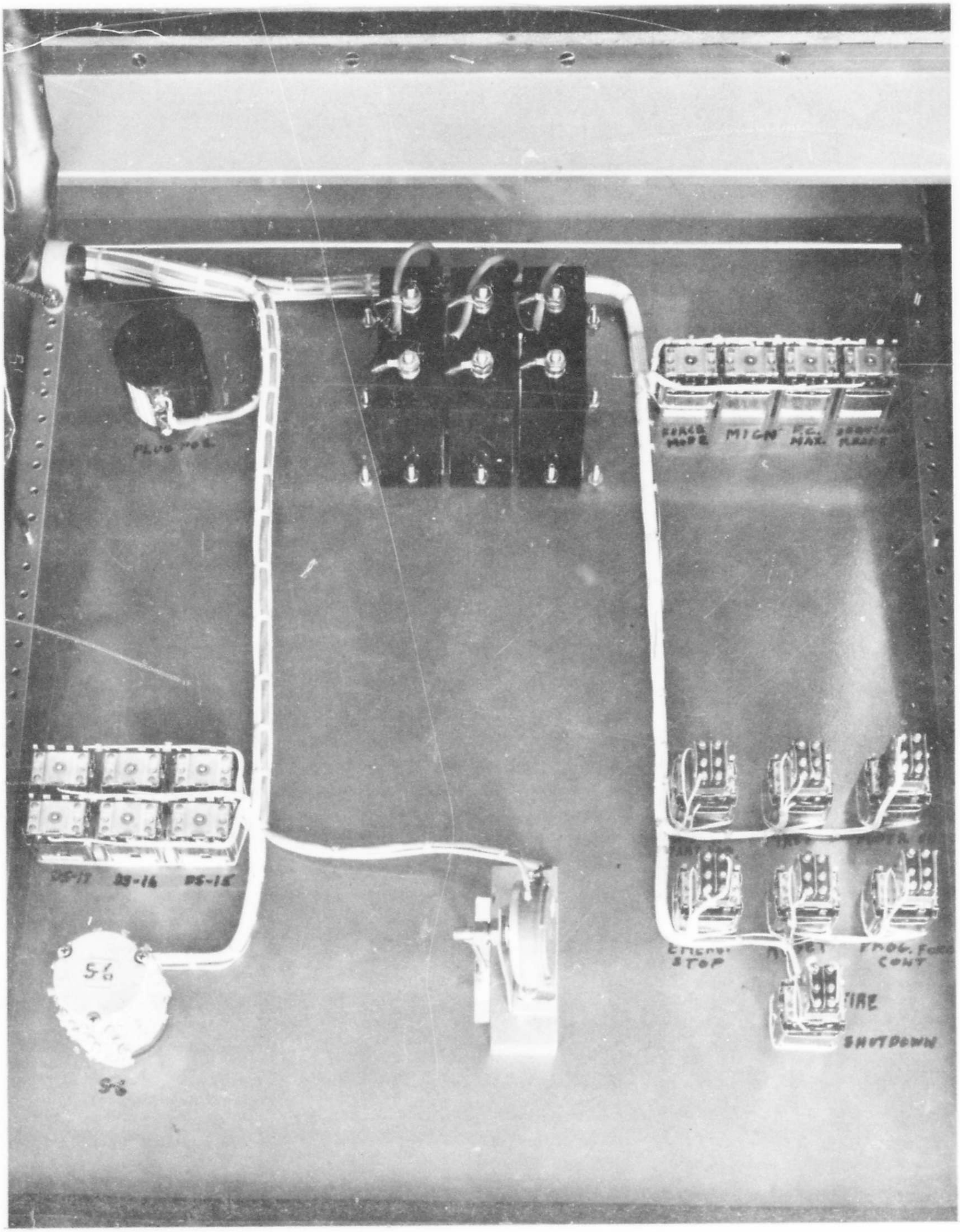


Figure 50. Console Sequence Circuitry

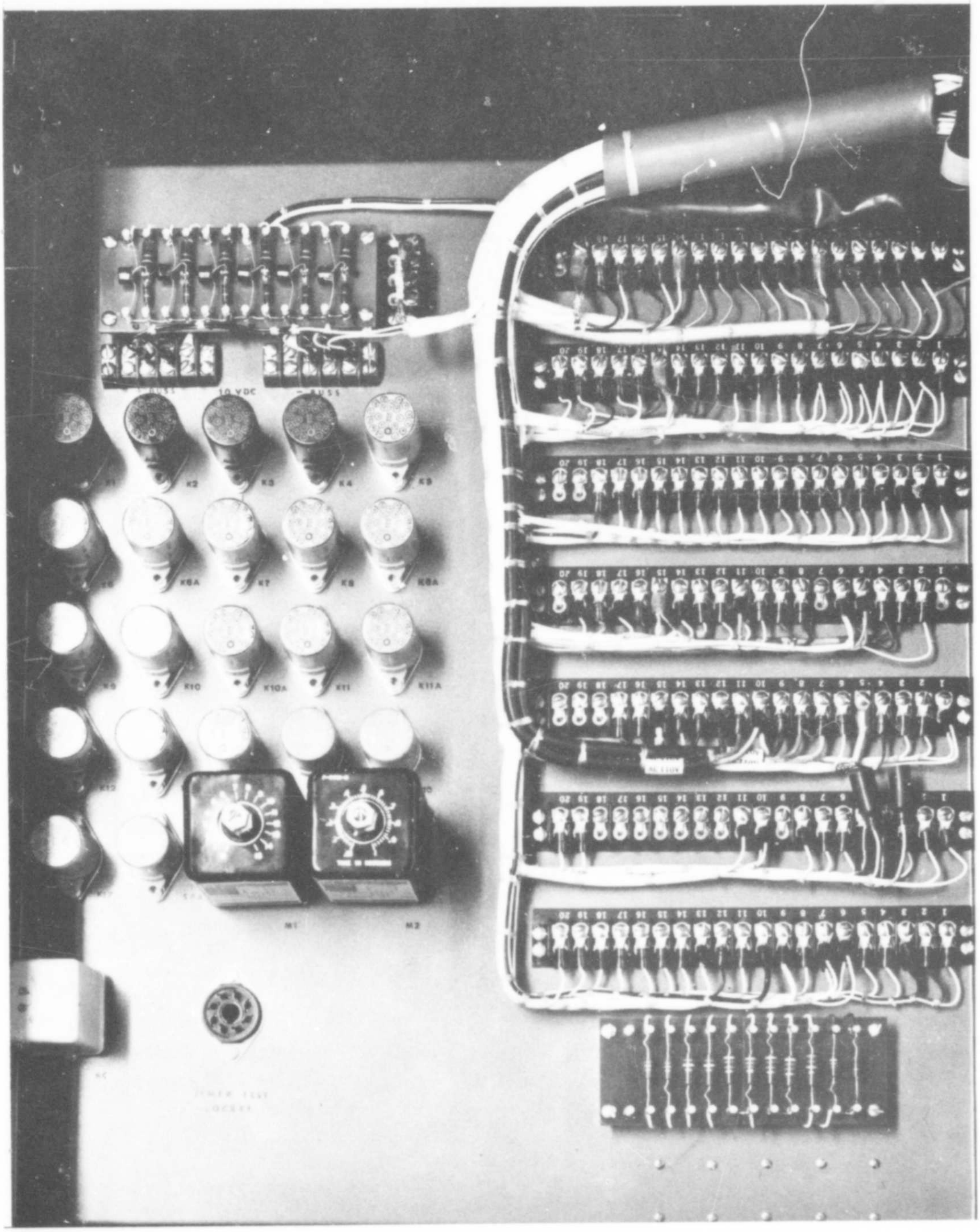


Figure 51. Console Sequence Circuitry

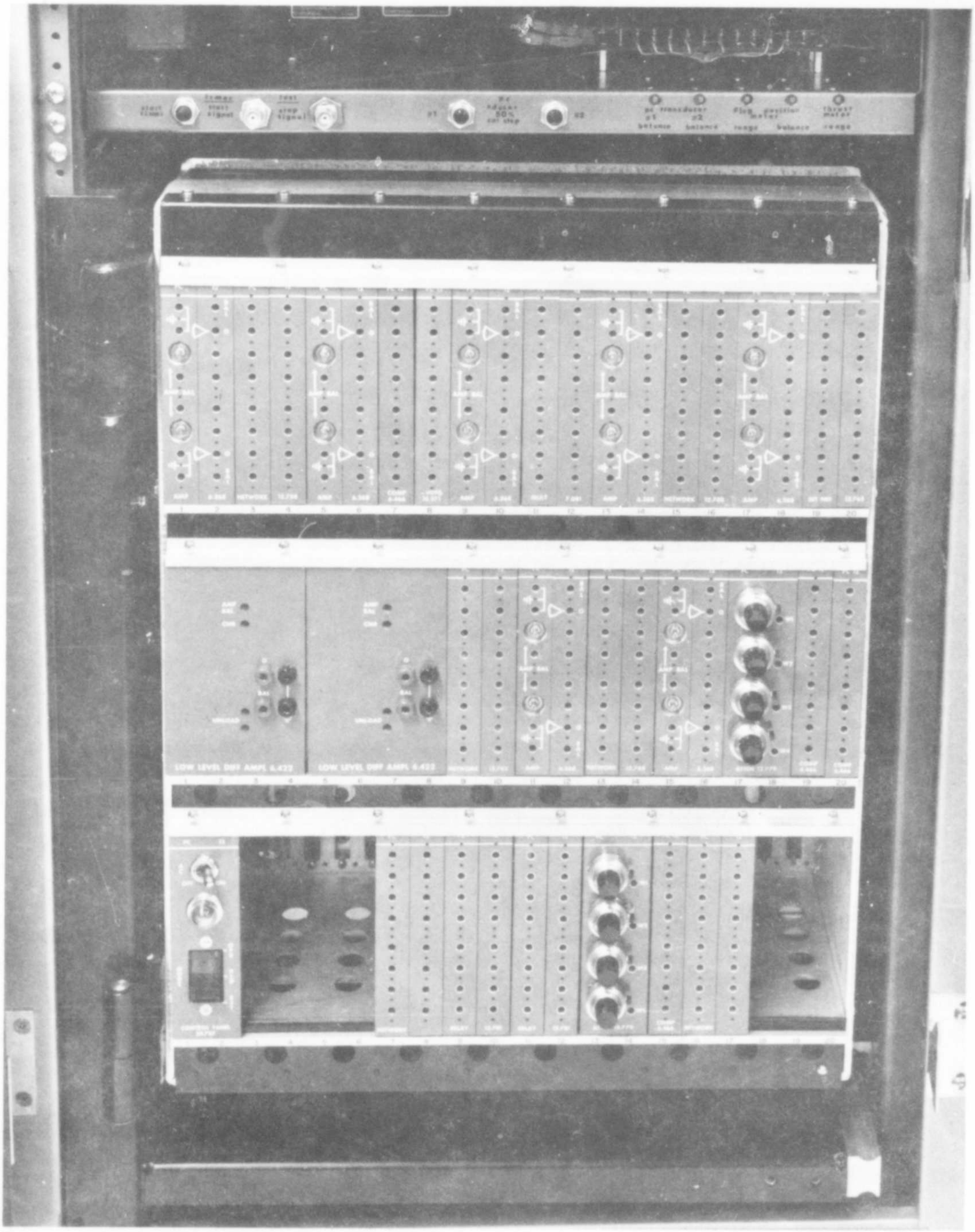


Figure 52. Console Computer Section

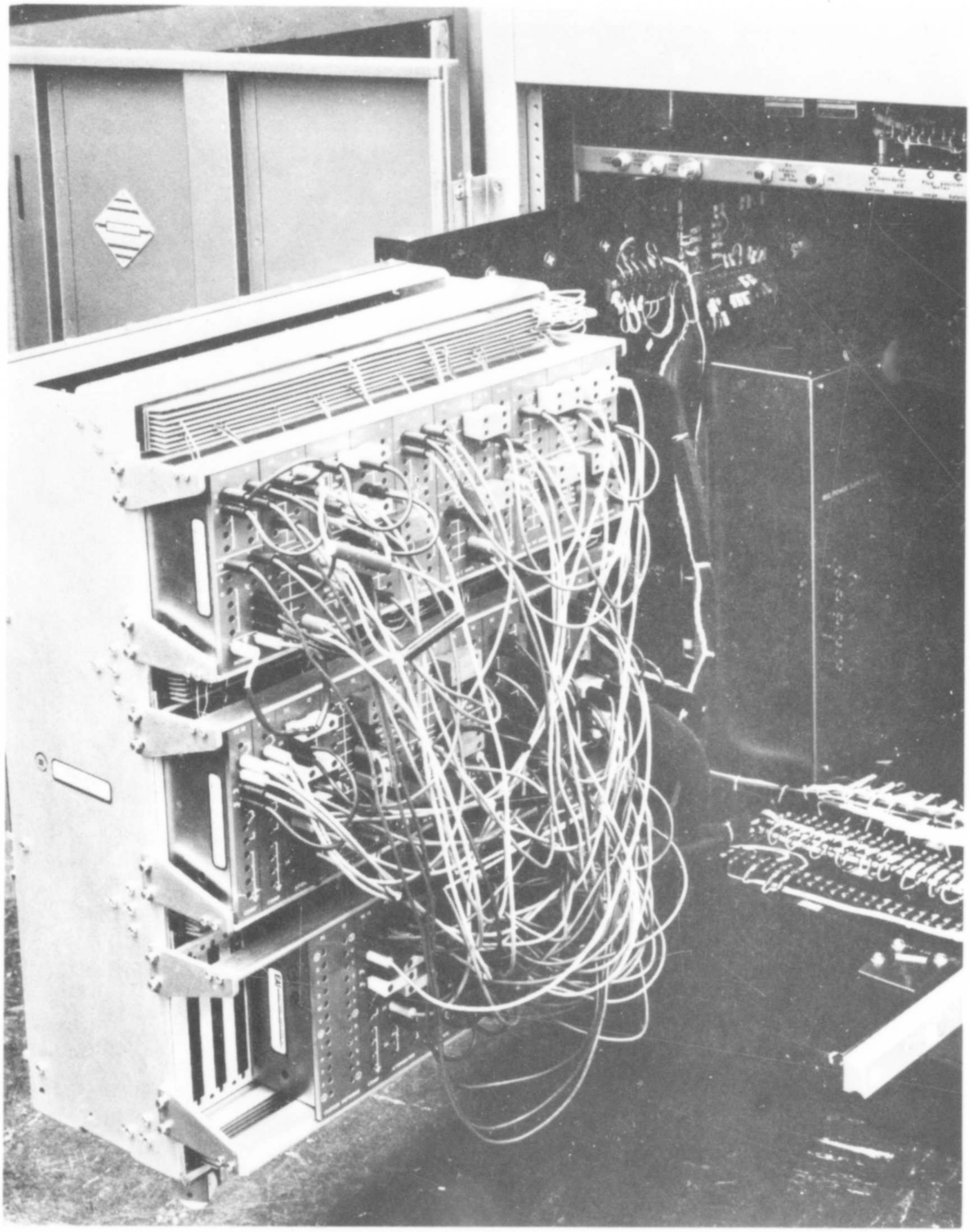


Figure 53. Console Computer Section

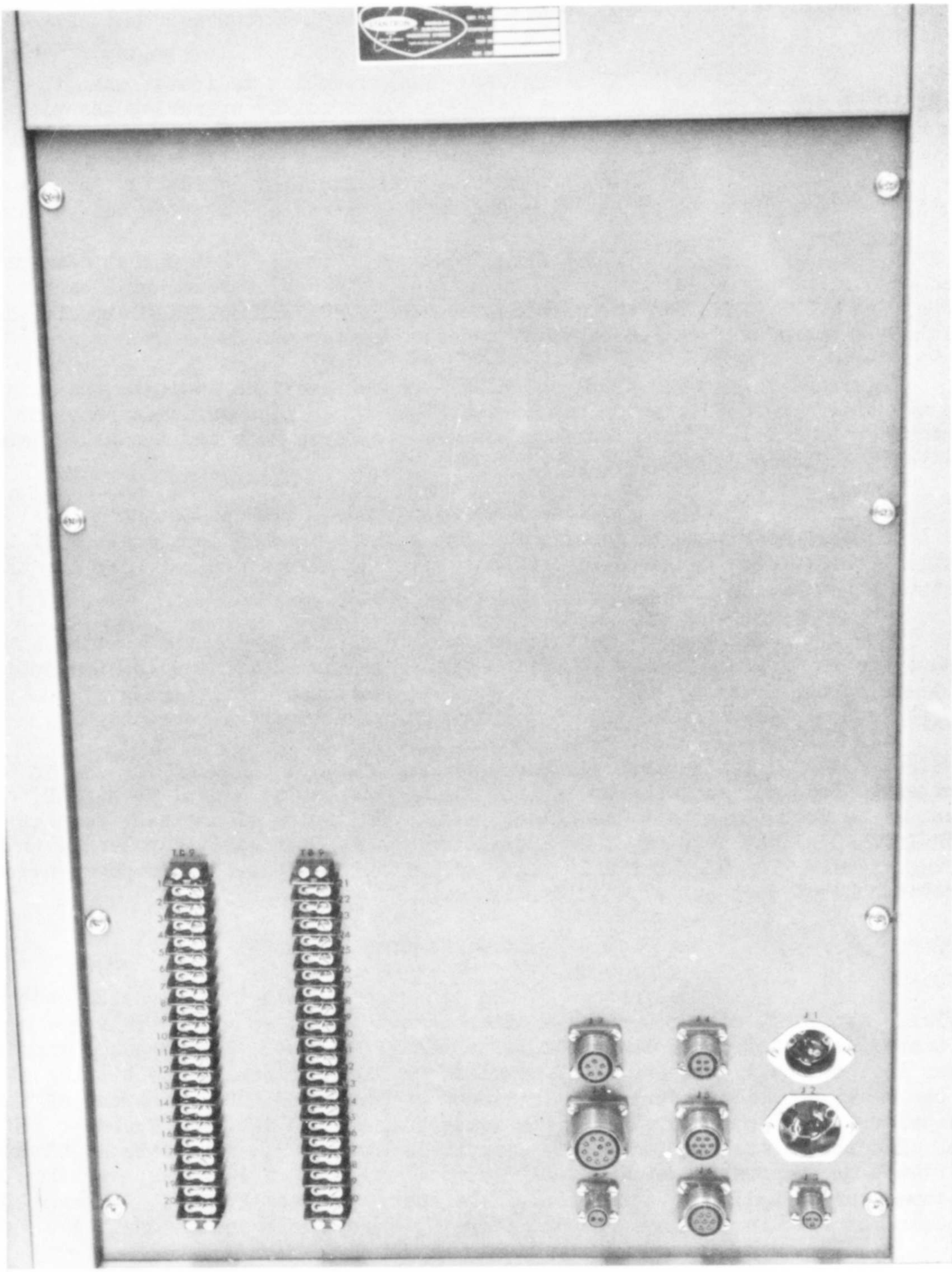


Figure 54. Console Interface Connection Panel

III, B, Special Test Equipment (cont.)

(1) FSM Energized - This function indicates when the failsafe manifold is energized and the servo valve is electrically operable, assuming that the hydraulic pressure is up.

(2) Sequence Ready - This function indicates that the proper chain of events prior to rocket fire has been achieved and igniter can be fired.

(3) TCPS - This function indicates that thrust chamber pressure switch has been actuated. A sustained chamber pressure will assure a timing out of the MTCPS TIMER and the combination "PRESSURE SWITCH-TIMER" circuit will initiate a transfer from the position mode to the force mode.

(4) MTCPS and MIGN - These functions indicate the time out of the two timers used in the circuits. The MTCPS timer is used in conjunction with a comparator to initiate transfer from position to force mode and the MIGN timer opens the igniter firing circuit.

(5) Position Mode/Force Mode - This indicator indicates the pintle control mode that is in effect. The position mode allows control of the pintle with the plug position Pot. The force mode allows control with the thrust control throttle.

The control section of the lid consists of 7 push button indicators a throttle lever and a rotary potentiometer. The push buttons allow the application of power to the console, arming, firing, and resetting. Positioning of the plug and thrust control are achieved with the rotary Pot. and throttle respectively.

The igniter selector switch allows selection of any one of 6 igniters. The igniter selected is indicated. The output signal is a 28VDC signal that may be used to actuate the select relay. On firing of the selected igniter the "IGN-X FIRED" light goes on, thus indicating the igniter circuit pulsed with the firing signal. The "IGN-X FIRED" light will stay on until console power has been removed. Reset does not affect the lights.

b. Sequence Circuitry, Figures 50 and 51

The purpose of the sequence circuit is to provide control of the failsafe manifold, plug position, igniter select, etc., so that a firing can be safely initiated, terminated and the motor restarted if desired. The sequence circuit provides initial position power to the failsafe manifold allowing positioning of the plug in the start position before the firing can be initiated. On placement of the plug in the proper position the signal to the failsafe manifold is transferred to the READY-MALF circuit and the sequence ready circuit is energized. Automatic shutdowns are initiated on the opening of READY-MALF circuit by loss of AC power, high Pc, loss of DC power, or manually, by actuation of the emergency stop button. The mode of the sequence circuit is displayed at all times by the console indicators. A timer check-

out circuit is incorporated in the console to facilitate checkout and setting of the two timers used in the sequence circuits.

c. Computer Section, Figures 52 and 53

Servo control is affected by the use of a Pace PC-12 analog computer consisting of the following components:

(1)	Dual DC Amplifiers	7 each
(2)	Lo Level Amplifiers	2 each
(3)	Relay Comparators	4 each
(4)	$(1/4)^2$ Multiplier	1 each
(5)	Integrator	1 each
(6)	Four Potentiometer Network	2 each
(7)	Variable Diode Function Generator	1 each
(8)	Quad Relay Module	2 each
(9)	Inverter Network	3 each
(10)	Custom Network	2 each

and respective patching modules. The servo control system operates in two modes, the position mode and the force mode utilizing two feedback loops.

Prior to the firing and during the start transient period the position mode is used to place the plug in the desired position. On decay or the start transient and in steady state, the system is automatically switched to the force mode. In the force mode thrust may be varied as desired by use of the thrust control throttle or by means of a programmed force input. The force feedback signal is obtained by sensing the plug position and converting it to throat area in the variable diode generator and multiplying it with chamber pressure in the $(1/4)^2$ multiplier. The error signal resulting from the summation of the demand force signal and the force feedback signal activates the hydraulic system controlling the nozzle movement. Optimum damping is achieved by use of proper amplifier gains.

The relay comparators are used to monitor the plug position and chamber pressure and to initiate switching signals to the sequence circuitry.

The lo - level amplifiers incorporate a gain of 333. The input to these amplifiers from the transducers monitoring the chamber pressure is increased to 10 volts maximum. A comparator circuit is used to monitor the Pc signal; the comparator circuit is adjusted to automatically switch to the transducer providing the highest Pc signal. This system minimizes the possibility of a low chamber pressure due to line clogging or single transducer failure.

Comparators are also used to monitor the plug position and to monitor levels of chamber pressure to initiate mode transfer or emergency shutdown due to excessive chamber pressure.

III, B, Special Test Equipment (cont.)

d. Console-Rocket Motor Interface Panel, Figure 54

The rear panel of the console is provided with terminal strips and connectors to provide interface with the rocket motor and with instrumentation for monitoring and recording purposes. The interface cables to the console required are as follows:

(1) 28 VDC 10 amps
(2) 115 VAC 1-phase 60 cycle 10 amps
(3) Thrust monitoring signal from instrumentation (10 VDC max.)
(4) Position feedback potentiometer
(5) Pc transducer #2
(6) Pc transducer #1
(7) Servo valve
(8) Igniter select relays and firing pulse to EBW unit
(9) Failsafe manifold
(10) Instrumentation signal for recording servo voltage, plug position, percent throat area, force feedback, chamber pressure Pc, and programmed force.

Connections are also provided on the rear terminal strip to allow a "hands off" firing of the motor by means of an external programmer i.e., the arming, firing and resetting of the console may be accomplished by external control.

e. Operation

The sequence circuitry allows positioning of the plug prior to rocket fire, for checkout, measurements or setup purposes. The sequence ready circuit ensures that the plug is in the proper position before igniter fire can be initiated. The READY-MALF circuit locks in the signal to the failsafe manifold and initiates the shutdown in case of a high Pc, loss of power or in case the emergency shutdown button is actuated. The emergency shutdown button can be used in case a relay in the shutdown circuit malfunctions.

Rocket extinguishment may be accomplished by either P-dot or L* commands. P-dot command extinguishment is accomplished by de-energizing the failsafe manifold; thus, the servo valve is bypassed and a hydraulic bias placed on the actuator rapidly driving the pintle to the shutdown position. The pintle may be shuttled to the shutdown position from maximum displacement in 50 milliseconds. P-dot command shutdowns are accomplished by pressing the Fire-Shutdown Switch or the Emergency Stop Switch. L* command shutdowns are accomplished by retracting the Thrust Control throttle towards the 0% position. As the Fire-Shutdown switch is an alternate action switch, Reset and Arming cannot be accomplished until the switch is placed in its initial position. This is indicated by a continous reset light.

Restart of the motor is accomplished by selecting an igniter, Resetting, Arming and applying power to the failsafe manifold. With hydraulic pressure up and the plug position potentiometer set, the plug will track to the start position and Sequence Ready. The sequence of operation is as follows:

III, B, Special Test Equipment (cont.)

(1) Computer on, switch in operate position.
(2) Apply console power. NOTE: Computer should warmup 15 minutes.
(3) Hydraulic power on and pressure up.
(4) Actuate "Initial Position Power".
(5) Arm
(6) Rotate plug position Pot. to place the plug in the start position; monitor on the plug position meter. Light will indicate plug in start position. Sequence ready light will indicate and malf light goes out.
(7) With proper igniter selected and indicated, fire switch can be made at will. NOTE: The thrust control throttle will have to be initially set at a predetermined value commensurate with the force generated by the rocket motor with the plug in the initial position.

On start, the "position mode" will be maintained for the duration of the start transient. TCPS (thrust chamber pressure switch) and its associated timer (MTCPS) will affect the transfer to the "force mode". Thrust control may be then utilized to vary the thrust of the motor either manually or programmed.

C. PROPELLANT RE-EVALUATION

(u) Propellant tailoring efforts had been terminated during the third quarter of Contract AF 04(611)-10820, after the second heavyweight motor test as it appeared that AAB-3220 propellant would meet the basic needs of the program. These first two tests demonstrated variable thrust at sea level and the second test, HW-2, demonstrated that the controllable solid rocket motor could be extinguished at sea level, although permanent extinction could not be maintained. On the basis of these tests, it seemed probable that some of the funds allocated to continue propellant tailoring could be diverted to areas elsewhere in the program that were indicating higher than estimated costs. The propellant work was halted at a point which would allow immediate re-instatement of this work with little loss of effort if such a move were indicated later in the program.

(c) With the firing of HW-3, Runs 003 and 004, it became apparent that AAB-3220 would be marginal in meeting the program requirements on the basis of both burning rate and P-dot extinguishment. Motor HW-2, fired during the third quarter of the program, indicated that the burning rate of AAB-3220 propellant in the 'Finocil' grain configuration used in the single-chamber controllable solid rocket motor was somewhat higher than would be expected from the 3KS-500 burning rate motors. Even taking into consideration the scaleup factor on the batch size, the burning rates at low pressures were considerable out of line. This factor, in itself, was not a major problem area so long as the propellant could be successfully extinguished at altitude. When motor HW-3, Run 004, could not be extinguished at what was thought to be in excess of 60,000 foot simulated altitude, a decision was made to reopen the propellant evaluation effort in an attempt to either find a different formulation which would better meet the needs of the CSR motor or to correct the burning rate difficulty with AAB-3220 so that the minimum chamber pressure attainable in the full-scale CSR would be low enough to permit reliable extinguishment. This propellant re-evaluation effort was thus initiated after a meeting with the Air Force technical personnel at AFRPL, Edwards Air Force Base.

(u) The propellant re-evaluation effort is divided into two separate tasks: (1) to re-evaluate AAB-3220 propellant in an attempt to solve the burning rate problem and determine the ballistic and extinguishment characteristics of this formulation in small motors that would be applicable to the full-scale CSR motor; and (2) to reopen the investigation of alternate formulations that had appeared promising during the earlier propellant tailoring effort.

1. Propellant AAB-3220 Retesting

(c) Some investigative work was immediately initiated as soon as it was determined that AAB-3220 could not be reliably extinguished in the full-scale CSR at altitude. This was started simultaneously with the investigations as to the other possible causes of the anomaly in HW-3, Run 004, that were previously discussed. During the course of the propellant investigations, it was postulated that

the burning rates that were determined in the 3KS-500 motors and the Crawford Bomb Motor (CBM) tests were low due to the heat loss to the surrounding environment, namely the chamber walls. Data that had been taken on the batch of propellant that was used in the first three heavyweight motors was compared to that back calculated from firing HW-2. These data are presented on Figure 55.

(c) From Figure 55, it is apparent that considerable deviation exists between the burning rates calculated from the CSR motor and those measured in the subscale motors, specifically at pressures below 100 psia. An attempt was made to calculate the mass flow coefficient of the propellant gas in the CSR motors. The values calculated, 0.0067 and 0.0063 1/sec, were in very good agreement with the theoretical value of 0.00658 1/sec that was predicted for this motor. As the theoretical value was used to back calculate the burning rate from the CSR and the only other values used were measured thrust and measured chamber pressure, it was determined that the values calculated were probably a very good indication of what could be expected in this motor. It was then hypothesized that reignition of the motor HW-2 was due to the higher temperature of the grain immediately after extinguishment and aided by the heat flux from the hot insulation. This higher temperature profile in the propellant may be the cause of the indicated high burning rate at low pressure. When this hypothesis was investigated, it was found that the burning rate for the first 0.60 seconds may be slightly higher than normal, however this effect could not possibly last for the 5 seconds that HW-2 indicated high burning rates.

(c) A second approach was to re-analyze the small motor firing data taken from the same batch as that cast into the first three heavyweight motors. These motors were 3KS-500 burning rate determination motors, using an internal and external burning cylinder of approximately 6 pounds of propellant. From the grain configuration, these firings should have been neutral; however, in each case they were slightly progressive, when fired at low pressures. The possibility of aluminum oxide deposition on the nozzle throat insert was investigated and found to be far too small to account for the progressivity. The only remaining possibility that would explain this progressivity is that the grain did not burn evenly and that the inside diameter burned at a higher rate than did the outside diameter. To further investigate this possibility, the ID-OD-End Burning grains were reinvestigated. These grains should burn regressively at a pressure regressivity of 28% as they have a surface area regressivity of about 13%. These firings, however, had only a 5% to 0% regressivity, thus they also burned more progressively than anticipated.

(c) The other type of grain used to measure burning rate is the Crawford Bomb Motor. This motor used small ID burning grains which are quire accurate at high pressures, but were also low at the low pressures. As these are internal burning grains, the fact that they were low eliminated the possibility that grain configuration was the cause of the burning rate discrepancy. It was,

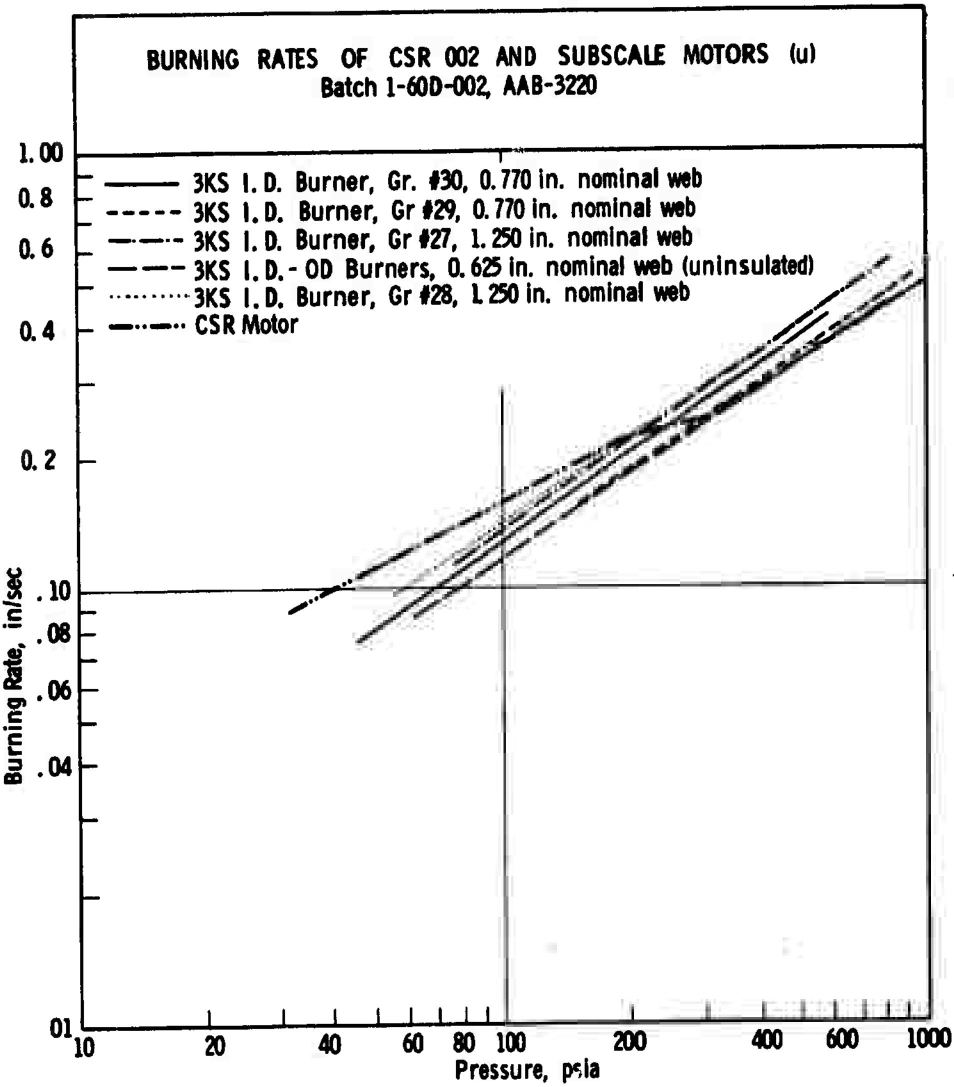


Figure 55. Burning Rates of CSR 002 and Subscale Motors (u)

therefore hypothesized that the cause of the low pressure burning rate discrepancy was heat loss to the motor case and nozzle in the small motors, depressing the burning rate. This theory appeared to be consistent with all of the small scale motor data, including the CBM. By calculating the difference in internal and external burning rates required to explain the progressive burning of a neutral grain configuration, it was found that the internal burning rate would have to be approximately 25% higher than the average burning rate that was quoted at the average pressure. Although this is not enough of a difference to explain the total deviation between the small motor and the full-scale CSR motor, it is definitely in the correct direction.

(c) Since the heat losses to the environment in the small motors consisted of a large percentage of the heat available in the propellant gasses, the parameter to be considered in the determination of burning rates at low pressures is the heat loss per unit mass flow. This parameter becomes progressively greater as the chamber pressure, thus the mass flow is decreased. This becomes a very important part of the P-dot and L* extinguishment process as the residence time of the gas in the chamber is increased as the pressure is lowered, thus the heat loss from any given amount of gas is increased as the pressure is lowered. It was therefore indicated that the P-dot and L* data that had been taken from the screening test motors was also probably not that which would be indicative of the full-scale motor.

(c) All of the small scale burning rate motors and the P-dot and L* screening test motors had been fired as uninsulated motor cases on previous programs with considerable success in predicting the performance. These tests, however, were all fired at high chamber pressures where the heat loss per unit mass flow is low. In conjunction with the Air Force, it was decided to repeat the testing of AAB-3220 at low pressures using insulated motor cases. These data, although still in process of being reduced, give an indication that the burning rates have not changed much from those fired in uninsulated motors. Considerable attention is currently being directed toward the selection of the appropriate insulation to use in these motors. It appears that the rubber insulations with fairly high heats of ablation and low conductivities are much better than the paper-phenolics although the latter are more readily available in the proper size tubes. The paper-phenolic insulations seem to absorb sufficient heat from the propellant gas to depress the burning rates almost as much as the bare steel chamber walls. When rubber insulation is used, the burning rates at low pressures come fairly close to those calculated from the CSR motor. For P-dot and L* screening tests, the extinguishment requirements are probably more sensitive to heat loss than are the burning rates, as even the paper-phenolic insulators were sufficient to indicate a definite difference in rates of depressurization required to extinguish propellant from those predicted in the uninsulated motor cases.

(c) Preliminary results of the re-running of the P-dot extinguishment screening tests of AAB-3220 propellant in insulated motor cases indicate

III, C, Propellant Re-evaluation (cont.)

that a higher than expected P-dot is required to be on the safe side of the extinguishment limit line. This P-dot is very close to the rate that the CSR can be expected to drop to when the motor free volume reaches its maximum value. Therefore, the margin of safety that was originally thought to be available in the CSR is now no longer present. Figure 56 depicts the P-dot screening test results of the insulated screening test motors.

(u) Work on AAB-3220 re-evaluation testing and data analysis will continue until the ballistic and extinguishment characteristics of this propellant have been established to a point that is felt to be consistent with the full-scale CSP requirements, that is data that will be indicative of the performance in the full scale motor. This will be done to assure that it is available in the event an alternate propellant formulation is not found suitable for use in the lightweight motors.

2. Alternate Formulations

(c) At the time that the propellant tailoring effort was stopped, there were a few alternate formulations that had not received as much work as AAB-3220 however appeared to offer lower rates of depressurization than AAB-3220 with about the same specific impulse. These formulations were all nitroplasticized polyurethane propellants containing nitro-guanidine as an auxiliary oxidizer. These formulations are shown below as compared with the current CSR propellant, AAB-3220.

	Propellant Compositions by Weight %			
Ingredient	AAB-3220	Batch-158	AAP-3249	Batch-467
AP	50.0	61.0	51.0	48.0
$KClO_4$	20.0	-	-	-
NQ	-	15.0	15.0	20.0
Al	16.0	2.0	10.0	10.0
NaCl	-	-	3.0	-
PBD	14.0	-	-	-
NPPU	-	22.0	21.0	22.0

(c) All of the above propellants have had some testing to date. The burning rates that were derived from the solid strand test method are shown on Figure 57. As can be seen from this figure, the burning rate of Batch-158 is indicated to be higher than that of AAB-3220. This by itself would require that the extinguishment characteristics of this formulation be quite a bit more easily attainable than those of AAB-3220. The burning rate of Batch-467 is lower than that of AAB-3220 at the high pressure end only. This is an undesirable characteristic in that all it will accomplish is to lower the maximum thrust level that can be attained with the CSR design as it now stands. As the burning rate of this

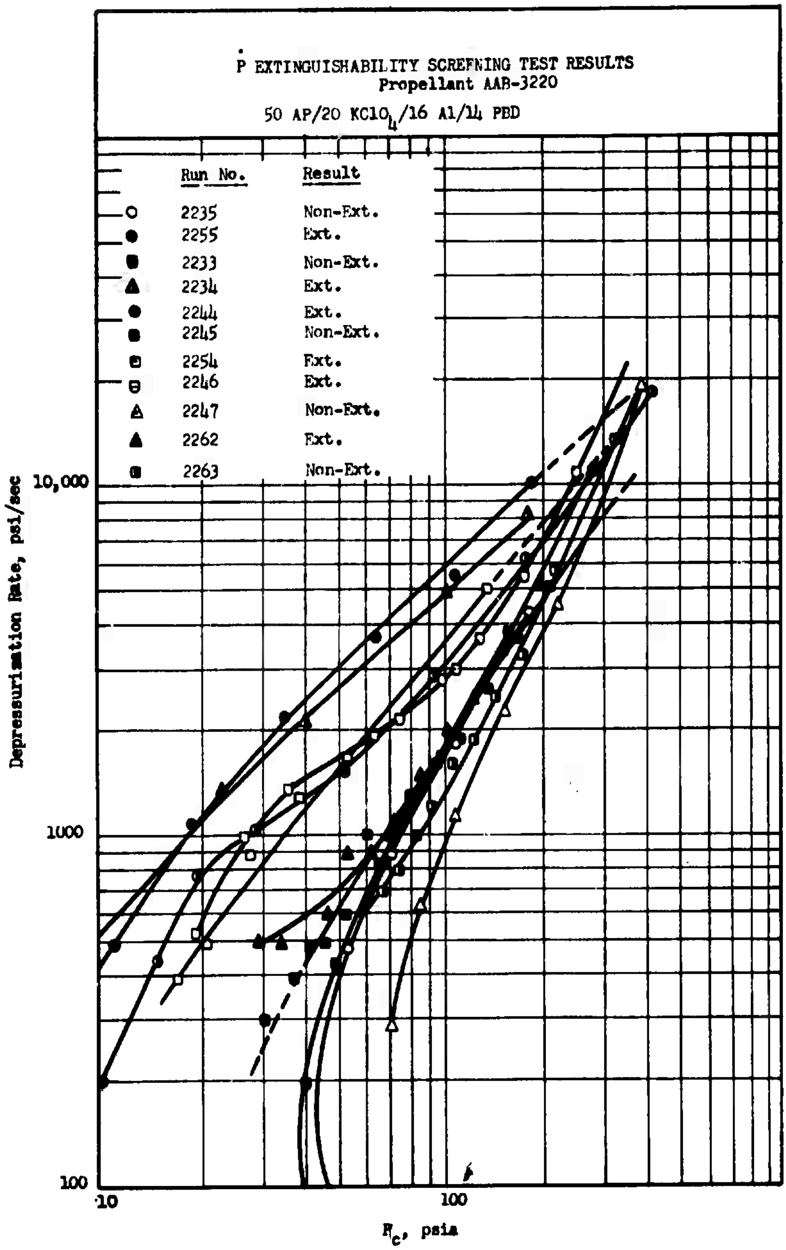


Figure 56. P-dot Extinguishability Screening Test Results (u)

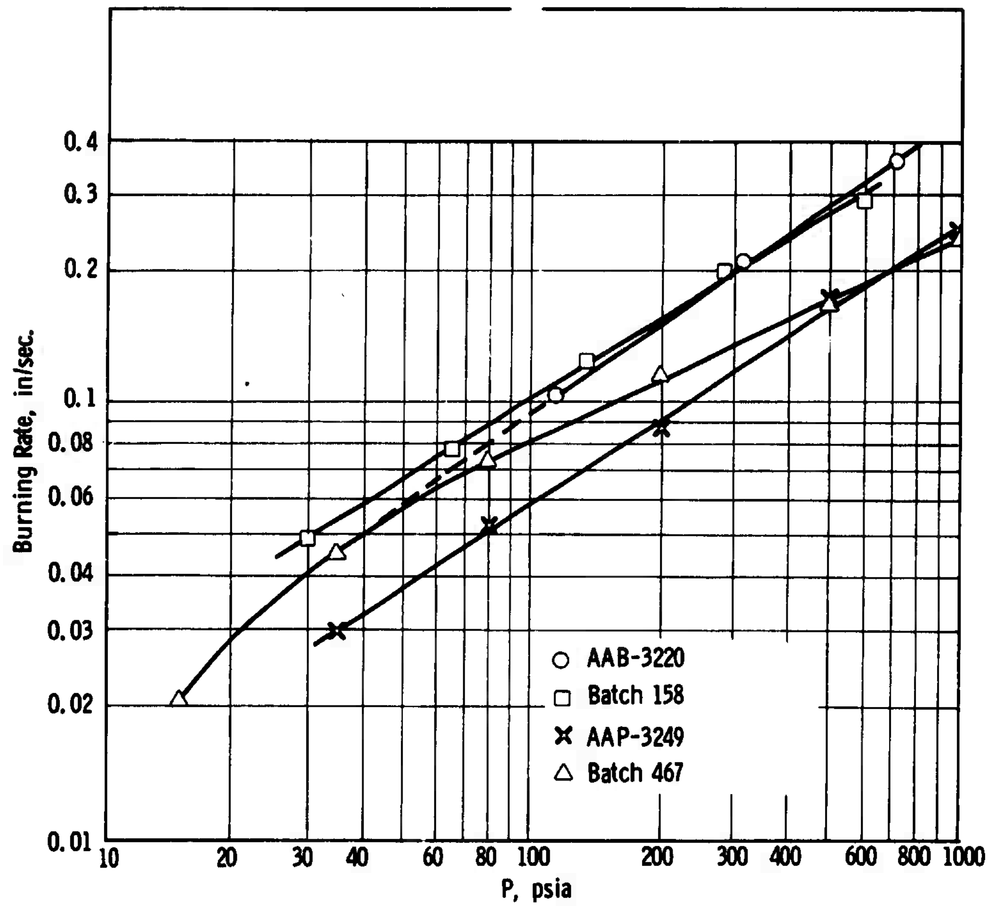


Figure 57. Solid Strand Burning Rates (u)

propellant is approximately the same as that of AAB-3220 at the low pressure end, the same minimum pressure attainable in the CSR with AAB-3220 would limit this Batch-467 formulation from attaining an L* extinguishment.

(c) The burning rate of AAP-3249 is in the correct relative position in the areas of low pressure, however, the high pressure characteristics are similar to Batch-467 with the same limitation on the maximum thrust level. AAP-3249 would be a fairly good selection from the thrust variation stand if it is as extinguishable as AAB-3220 in that the minimum pressure attainable in the CSR motor as now designed is less than 10 psia. The limitation at the high pressure end could be easily eliminated for a propellant with so low a burning rate at the low pressure end of the scale. A simple change in the diameter of the outer throat insert would drastically reduce the nozzle minimum throat area without materially affecting the maximum throat area. The minimum area is now approximately 6.25 square inches and the maximum throat area is approximately 28.5 square inches for the lightweight series. By decreasing the minimum area by 2.25 square inches, the chamber pressure and maximum thrust attainable would be greatly increased with only a 2.25 square inch change to the 28.5 square inch maximum area. This would limit the minimum pressure attainable to approximately 14 psia -- only a 4 psi change.

(c) The extinguishment characteristics of these three alternate propellants are quite different. In the first place, all are apparently more easily extinguished by P-dot than is AAB-3220. Each has a definite "break-even-venting-line" where half of the motors fired are permanently extinguished and theother half fail to extinguish. These P-dot versus P traces are presented for Batch-158, AAP-3249, and Batch-467 on Figures 58, 59, and 60, respectively. From these data, it can be seen that AAP-3249 is the most easily extinguishable of the three, with a P-dot requirement of about -300 psi/sec at 100 psia as compared to Batch-158 with a P-dot requirement of -1800 psi/sec and Batch-467 with a requirement of about -600 psi/sec at 100 psia. As these tests were conducted in the insulated chambers described above, they are considered to be fairly good indicators of what can be expected in the full-scale CSR motor.

(u) Although all three propellants are acceptable from an extinguishability standpoint, and each has the physical properties required by the CSR grain configuration, and the specific impulse required, all three have a potential burning rate problem. Only AAP-3249 has a direct solution to this burning rate problem with a relatively simple and inexpensive change. The selection of the alternate propellant for the CSR to be incorporated in the next three motors will not be made until mid-July 1966. This decision will be based upon a number of factors that have not been covered. Some of these other factors are (1) the oxygen balance and its effect upon the nozzle materials, (2) the cost of the propellant raw materials, (3) the castability of the propellant without unbondedness and voids (this differing from the simple stress considerations), (4) the scaleup factors of the new propellant and its effect upon burning rate and extinguishability, and (5) the ignitability of the propellant since the ignition system of the CSR motor for contract AF 04(611)-10820 is at this time a fixed item. All of

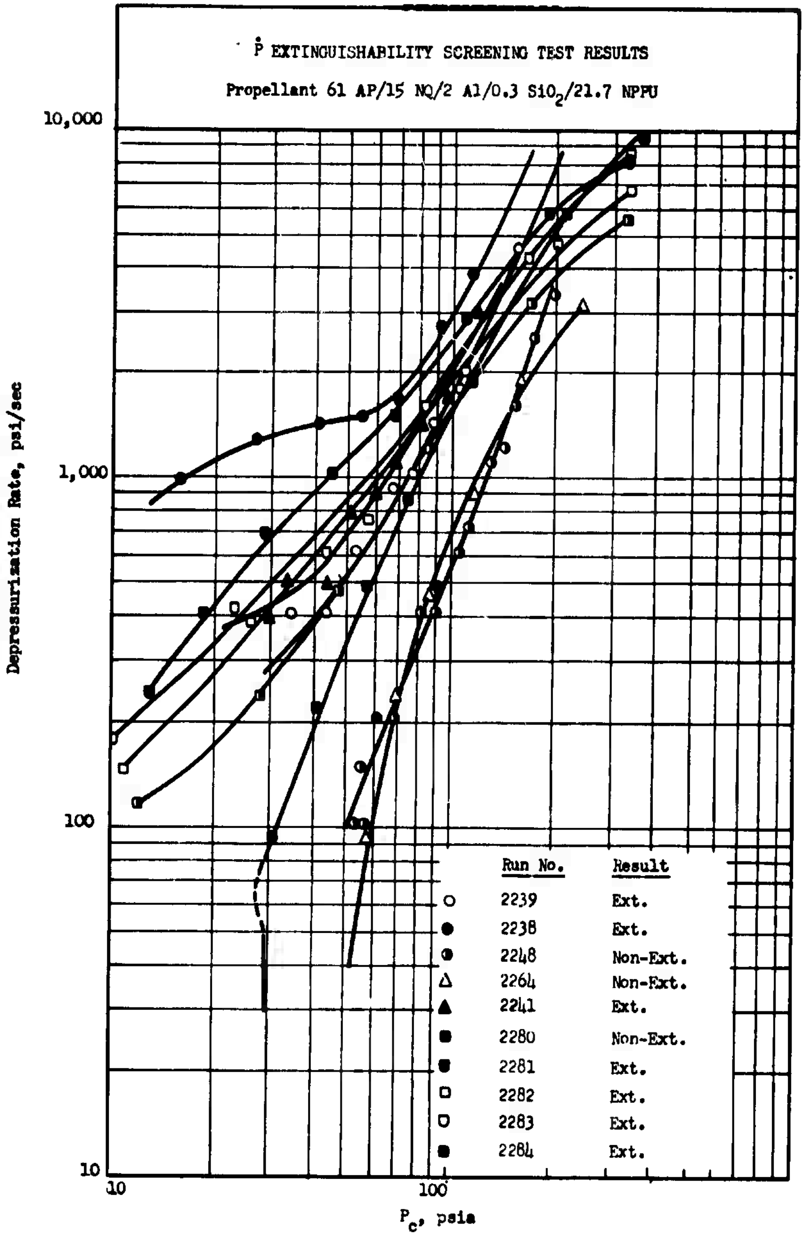


Figure 58. P-dot Extinguishability Screening Test Results (u)

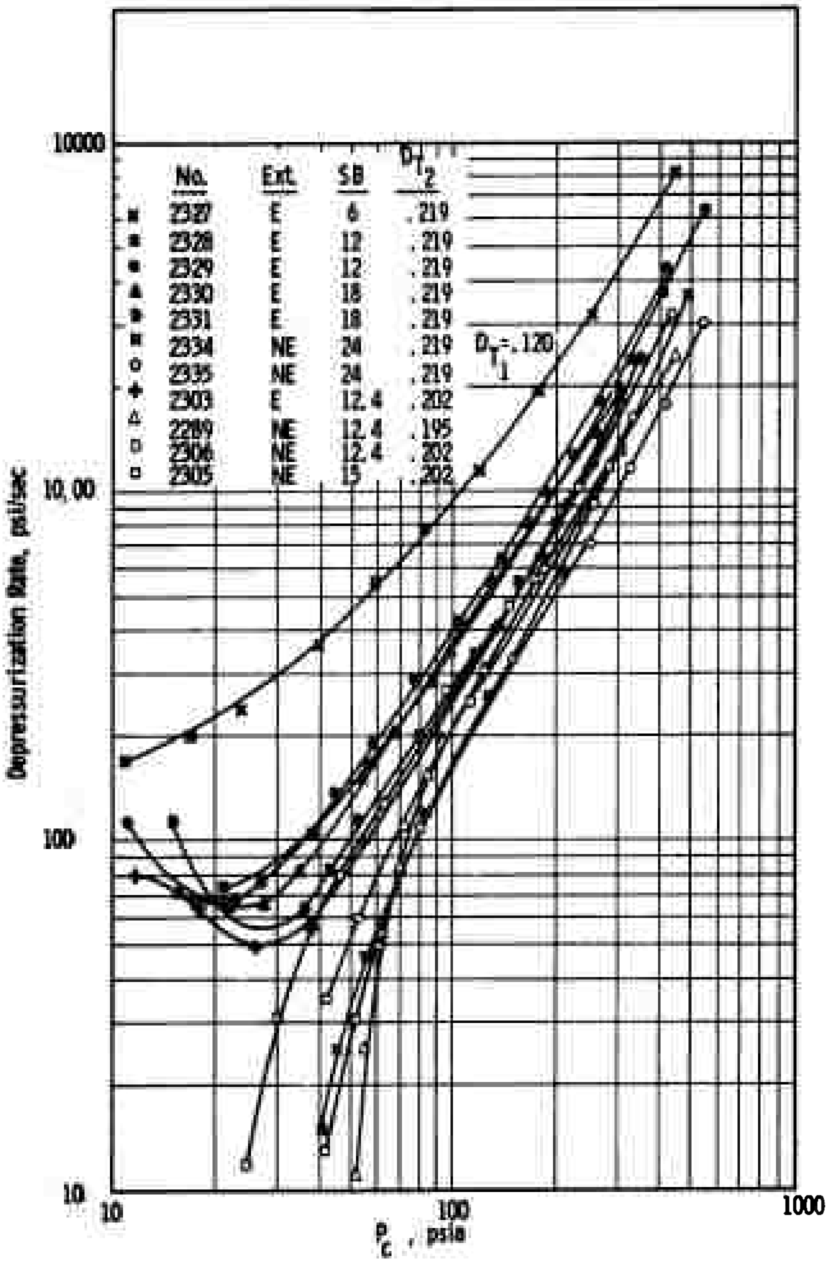


Figure 59. P-dot Extinguishability Screening Test Results (u)

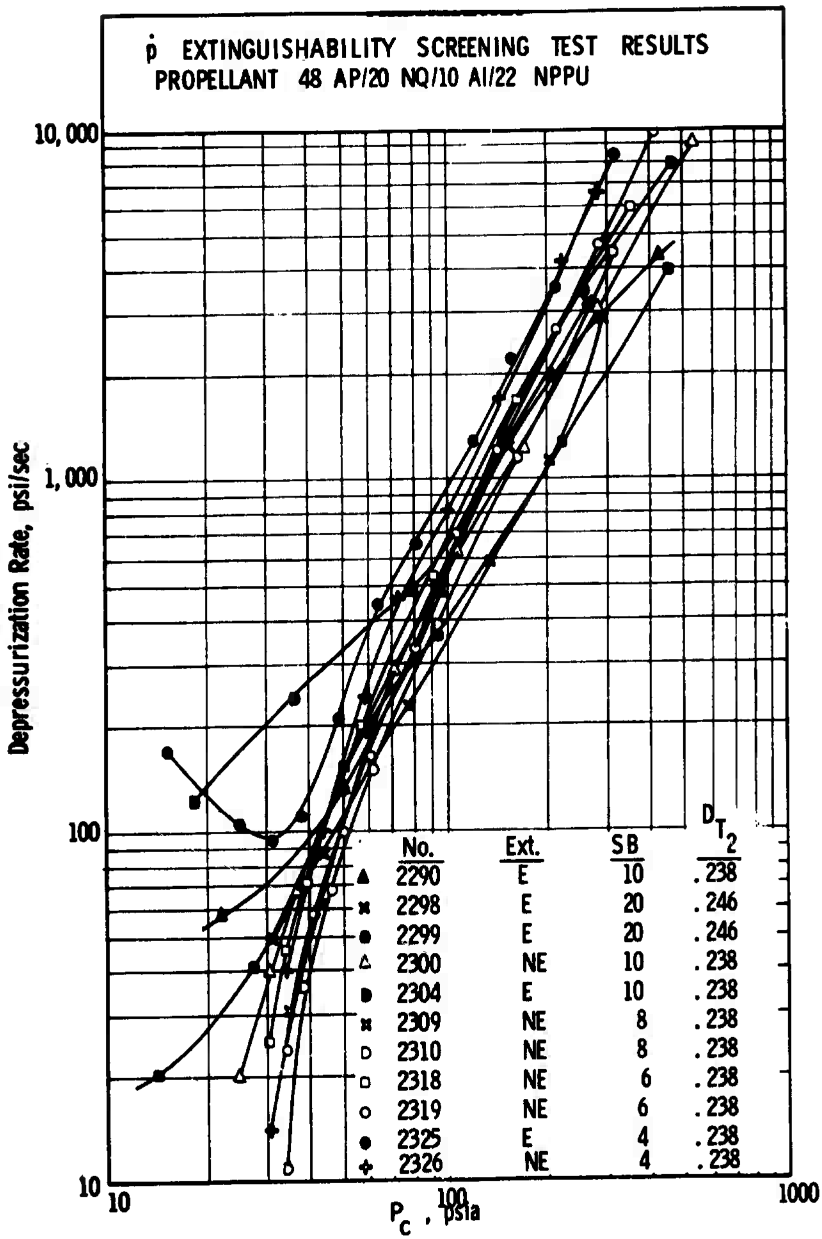


Figure 60. P-dot Extinguishability Screening Test Results (u)

these factors will play a role in the selection of the new propellant or the decision to revert back to the same AAB-3220 and short cast motors to insure extinction.

(u) Once the decision on the CSR propellant for the lightweight motor series is made, the propellant re-evaluation effort will be continued at a low level of effort in preparation for future combustion problems in the event that they should occur. This problem, although unfortunately timed in its occurrence, has had the benefit of pointing out the discrepancy between burning rate and extinguishability of propellants tested in small uninsulated motors and those expected in full-scale motors fired at low pressures. An acceptable solution to this problem has yet to be found, however now that it is known to exist, precautions can be taken to limit its effect upon motor development programs.

IV.

FUTURE WORK

Only three items of major importance remain to be accomplished through the last six months of contract AF 04(611)-10820. These three items are (1) Lightweight Motor Development, (2) AEDC Motor Deliveries, and (3) Analytical Studies. The heavyweight motor development program has been completed with a high degree of success, the only anomaly being the failure to achieve more than one successful extinction of HW-3. The work remaining in these three areas is outlined briefly below.

A. LIGHTWEIGHT MOTOR DEVELOPMENT

In this task, a lightweight nozzle design will be developed using the same ignition system, the same motor case hardware, and approximately the same grain and insulation design that was proven successful in the heavyweight motor. During the next quarter, the first three lightweight motors will be processed, assembled and test fired. The first two motors will be tested at sea level for variable thrust and the possibility of sea level extinguishment. The third motor will fire in the simulated altitude facility and will be used to attempt four remote thrusting cycles. All three of these motors will be directed toward proving the design of a lightweight pintle system. If this system proves to be acceptable, it will be used on the remaining three lightweight motors and on the two motors scheduled for test firing at AEDC, Tullahoma, Tennessee.

B. AEDC MOTOR DELIVERIES

Although these motors will not be assembled and shipped during the next quarter of technical effort, the hardware for these motors will be purchased, thus the design must be frozen during the next three months. In addition to freezing the design of the final lightweight motors and those to be delivered, a motor specification preparation will commence. This specification will list the components of the motor, the design points, the expected performance of the motor, and instructions for operation of the pressure feedback control system.

C. ANALYTICAL STUDIES

During the next three months, some analysis of the present CSR motor will commence to establish scaling factors necessary for any re-configuration of the single-chamber controllable solid rocket motor. All of the test firings to date, including the 3KS-500 burning rate motors and the CSR subscale motor tests, will be reevaluated to establish these scaling parameters. Special consideration will be given to the operational response that was attained during all of the variable thrust and extinction test firings as this may become an important parameter for motors of different size and shape. Mass fraction as a function of motor size will be another of the factors considered in review of the performance of the CSR motor to date.

AFSCR 80-20

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Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)

Aerojet-General Corporation
P.O. Box 15847
Sacramento, Ca. 95813

2a REPORT SECURITY CLASSIFICATION
CONFIDENTIAL

2b GROUP
4

3 REPORT TITLE
FEASIBILITY DEMONSTRATION OF A SINGLE-CHAMBER CONTROLLABLE SOLID ROCKET MOTOR (u)

4 DESCRIPTIVE NOTES (Type of report and inclusive dates)
Fourth Quarterly Report 1 April - 30 June 1966

5 AUTHOR(S) (Last name, first name, initial)

Levinsky, Charles T.
Kobalter, Gerald F.

6 REPORT DATE
July 1966

7a TOTAL NO OF PAGES

7b NO OF REFS

8a CONTRACT OR GRANT NO.
AF 04(611)-10820

b. PROJECT NO

c

d

9a ORIGINATOR'S REPORT NUMBER(S)
AFRPL-TR-66-164

9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10 AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES

12 SPONSORING MILITARY ACTIVITY
Air Force Rocket Propulsion Laboratory
Edwards Air Force Base, California

13 ABSTRACT (u) This report deals with the technical effort conducted during the fourth quarter of Contract AF 04(611)-10820, Exploratory Development of a Single-Chamber Controllable Solid Rocket Motor. During the first 3-quarters of this program a preliminary design phase, a propellant development phase, a subscale motor design and development phase, and part of a heavyweight motor development phase were conducted. Work performed in this area was reported in AFRPL-TR-65-204, AFRPL-TR-66-12, and AFRPL-TR-66-99. This report covers the completion of the heavyweight motor development effort, the lightweight motor design effort and the propellant re-evaluation effort. The final heavyweight motor test results are presented along with the data plots and photographs. This motor was fired at simulated altitude and successfully extinguished once. The second attempt at extinguishment failed due to a facility problem with the diffuser, trap-door, and external motor insulation. As a result of this firing, the diffuser and altitude facility are being modified, the propellant re-evaluated, and the test plan modified to avoid a recurrence of the anomoly. Some of the propellant re-evaluation has been compteted and is reported in this document.

DD FORM 1 JAN 64 1473

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14 KEY WORDS	LINK A		LINK B		LINK C	
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Third Full-scale Motor Test Results First Full-scale Motor Extinguishment Propellant Re-evaluation for CSR Motor Pressure Feedback Control Console Complete						

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